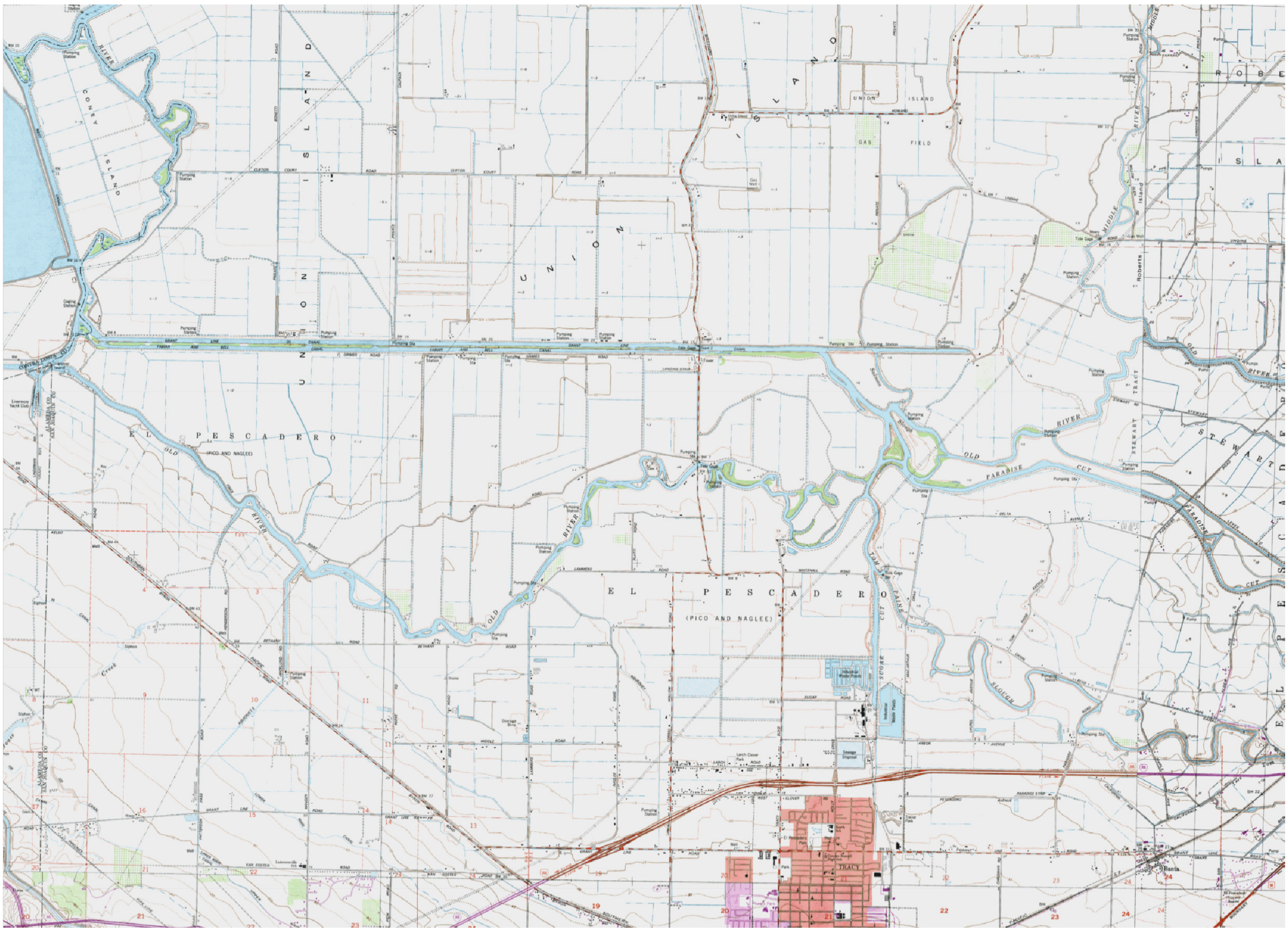
State of California
Natural Resources Agency
Department of Water Resources

South Old River Salinity Transect Study

Technical Memorandum Report



September 21, 2012

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DEPARTMENT OF WATER RESOURCES
Division of Operations and Maintenance
State Water Project Operations Support Office
Environmental Assessment Branch
Sacramento, California

Cover:
USGS 7.5-minute quadrangle of the southern Sacramento-San Joaquin Delta encompassing South Old River

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OFFICE MEMO

TO: Anthony Chu, Chief, Environmental Assessment Branch, Division of Operations and Maintenance	DATE: **September 21, 2012** SUBJECT: Memo Report: **South Old River Salinity Transect Study**
FROM: Barry L. Montoya, Staff Environmental Scientist Aaron Cuthbertson, Environmental Scientist	

Summary

Located in the southern Sacramento-San Joaquin Delta (Delta), South Old River (SOR) is a tidal waterway affected by multiple saline inputs. The State Water Resources Control Board (State Water Board) issued a cease and desist order to the Department of Water Resources (DWR) and U.S. Bureau of Reclamation (Reclamation) in response to “threatened violations” of the salinity objectives in SOR at the Tracy Boulevard Bridge compliance station (SWRCB 2006B). Maintenance of Delta salinity objectives is one component of the State Water Board’s Water Right Decision 1641 (D-1641, SWRCB 2000). D-1641 stipulates the terms and conditions of diversions by DWR and Reclamation intended to maintain Delta water quality standards. Reclamation and DWR were required to take corrective actions to obviate the “threatened violations” (SWRCB 2010). Actions included studying the feasibility of interim salinity control measures to comply with the objectives prior to the completion of the State Water Board Bay-Delta Plan review. Surface-salinity transects were conducted in SOR over a two year period to better characterize water quality impacts from discharge and tributary inputs. The objective was to provide a detailed analysis of salinity throughout SOR with a focus on inputs influencing the Tracy Boulevard Bridge compliance station where water quality standards have been applied.

South Old River generally extends east-to-west from the San Joaquin River to the approach channel to C.W. “Bill” Jones (Jones) Pumping Plant. Water from the San Joaquin River enters the head of Old River and continues west to the bifurcation with Doughty Cut where it’s routed to Grant Line Canal or down the SOR main stem. South Old River and its tributaries are the receiving waters for approximately 50 discharges, most of which are associated with drainage from agricultural lands. Many of the discharges have been monitored and exhibit elevated salinities due to the leaching of heavily mineralized resident soils from agricultural activities and groundwater (DWR 2007).

Conductivity fluctuated throughout SOR during each transect run; some trends were consistent between runs but many were not. Conductivity increased with distance downstream during all transects, reaching a peak near the western end of each run before declining from the influx of lower salinity water shifting up the river with tidal flow. The lower salinity water originates from the north via cross-Delta waterways and/or

Grant Line Canal drawn by south Delta export pumping (DWR 2004). Although all input sources (discharges and tributaries) identified in this study potentially contributed to the total salt load entering SOR, fewer than a dozen measurably affected transect conductivity. The measured effects by one or a combination of input sources included isolated slugs/spikes, stepped increases, or gradually rising trends. Specific trend and corresponding input locations were linked by linear referenced meter, the standardized distance in meters from the eastern transect boundary at the head of Middle River (meter zero).

The compliance station at Tracy Boulevard Bridge was repeatedly influenced by the transitory nature of passing impacted waters from upstream sources that resulted in wide-ranging conductivity fluctuations and increases. Conductivity was highest farther downstream due to the continued accumulation of additional saline inputs. Trends and sources are discussed below based on their position upstream or downstream of the compliance station at meter 10,927.

Upstream of Compliance Station

Some of the largest isolated conductivity slugs flowing down SOR originated from Paradise Cut (meter 6,400), a major tributary with a watercourse extending 12 kilometers (~7.5 miles) upstream to Paradise Dam. Paradise Cut serves as an overflow bypass channel for San Joaquin River floodwaters. Groundwater discharges were shown to be a major source of elevated salts to this waterway. Numerous agricultural drains also contribute to the salt load. Abridged transects (traversing a short segment of river several times during a tidal cycle) revealed that saline water from Paradise Cut was periodically drawn into SOR on a declining tidal stage. The resulting slugs of high conductivity were initially transported upstream before reversing direction near the tidal trough. As they moved downstream, the slugs often remained intact with minimal dispersion causing wide fluctuations at the Tracy Boulevard Bridge compliance station – observed crests were as much as 123% of background levels. Alternately, the slugs could be decayed by secondary meander channel outflows and tidal dispersion that, combined with successive downstream-flowing slugs from previous tidal cycles, resulted in stepped increases near the compliance station. One set of abridged transects documented an increase of 27%. Tidally induced conductivity slugs also originated from another major tributary, Tom Paine Slough, presumably when the unidirectional siphons had been inactivated.

The compliance station is situated just downstream from Tracy Boulevard Bridge Drain (meter 10,450), a relatively large pumped conveyance for saline agricultural drainage. Discharges routinely impacted conductivity at the compliance station due, in part, to its proximity immediately upstream (477 meters). Pumping was intermittent and assumed to be actuated by water level in the collector drain. When pumping, it generated localized plumes of fluctuating conductivity as discharge water gradually mixed with lower salinity river water. Broad slugs of high conductivity formed that temporarily stagnated near the compliance station with tide. The discharge – in conjunction with bidirectional tidal flux – was also shown to create stepped increases and gradually rising trends.

Downstream of Compliance Station

Bethany Road Drain (meter 17,747) is a pumped conveyance for agricultural drainage and possibly other source waters. This drain was shown to be a primary source generating large, broad zones of high conductivity often detected in western SOR. Discharges accumulate in a long secondary meander channel during incoming tidal flows and then become drawn into SOR upon flow reversal. Over several tidal cycles, the same segment of water in SOR moves back and forth past the convergence multiple times, repeatedly becoming dosed with meander outflows. In this manner, the zone may be maintained or grow in size depending on numerous potentially influencing factors such as the magnitude of salt loading, in-channel flow, tide, etc.

Maximum transect conductivities in western SOR ranged from 639 to 1,391 μS/cm, a 52 to 444 μS/cm increase (5% to 125%) over initial levels. The increases were largely attributable to the cumulative impact of multiple saline sources and one major discharge (Bethany Road Drain) centrally located within the zones of maximum conductivity. The maximums were positioned between meters 13,673 and 21,243 – all upstream of the temporary barrier installation site at meter 22,415. These positions were inversely correlated with tidal stage when excluding data within the barrier installation period. The relationship describes a constant re-positioning with tide of maximum salinity zones in western SOR.

Conductivity declined at the westernmost end of all SOR transects due to dilution from lower salinity water shifting up the river with tidal flow. The lower salinity water originates from the north via cross-Delta waterways and/or Grant Line Canal drawn by south Delta export pumping (DWR 2004). Saline outflows from SOR were diluted and eventually intercepted by exports, terminating their continued migration into the Delta.

Therefore, although the compliance station at Tracy Boulevard Bridge was routinely impacted by several saline discharge or tributary inputs, the greatest impacts (highest conductivities) were measured farther downstream due to the accumulation of multiple other inputs. Based on the data presented here, no one location along SOR is suitable for providing conductivity measurements that are representative of the entire waterway.

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Acronyms and Abbreviations

af	acre-feet
Bay-Delta Plan	Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary
Bryte Lab	Bryte Chemical Laboratory
°C	temperature in degree Celsius
Ca	Calcium
CDEC	California Data Exchange Center
cfs	cubic feet per second
Cl	chloride
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
Delta	Sacramento-San Joaquin Delta
DHS	California Department of Health Services
DMC	Delta-Mendota Canal
DWR	California Department of Water Resources
HCO_3	bicarbonate
km^2	square kilometer
meq/L	milliequivalents per liter
meter zero	eastern transect boundary at the head of Middle River
Mg	magnesium
mi^2	square mile
Na	sodium
NTU	nephelometric turbidity unit
OLD	station identification for CDEC automated monitoring station in South Old River at Tracy Boulevard Bridge
pH	negative log of the hydrogen ion activity
Reclamation	U.S. Bureau of Reclamation
SO_4	sulfate
SOR	South Old River
State Water Board	State Water Resources Control Board
SWP	State Water Project
taf	thousand acre-feet
TDS	total dissolved solids
TPS	station identification for CDEC automated monitoring station in Tom Paine Slough above the mouth
µg/L	micrograms per liter
µmole/L	micromoles per liter
µS/cm	microsiemens per centimeter
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

I. Introduction

Problem Description

The Department of Water Resources (DWR) operates the State Water Project (SWP) and is authorized by the State Water Resources Control Board (State Water Board) to divert water from the Sacramento-San Joaquin Delta (Delta). Water Right Decision 1641 (D-1641), adopted by the State Water Board in 1999 and amended in 2000, stipulates the terms and conditions of diversions intended to maintain the beneficial uses of Delta waters (SWRCB 2000). One particular condition requires the maintenance of salinity objectives at several compliance stations around the Delta for agricultural uses. The State Water Board issued a cease and desist order (Order WR 2006-0006, SWRCB 2006B) against DWR and the U.S. Bureau of Reclamation (Reclamation) for "threatened violations" of these objectives at South Old River's (SOR) Tracy Boulevard Bridge compliance station. The agricultural objective for conductivity is 700 µS/cm from April through August and 1,000 µS/cm from September through March (2006 Bay-Delta Plan, SWRCB 2006A). Reclamation and DWR were required to take corrective actions to obviate the "threatened violations" (Order WR 2010-0002, SWRCB 2010). Actions included studying the feasibility of interim salinity control measures to comply with the objectives prior to completion of the State Water Board Bay-Delta Plan review. The review (not finalized at the writing of this report) will determine whether or not changes are needed to southern Delta salinity objectives or the associated program of implementation based on technical and environmental analyses (SWRCB 2010).

Background

Located in the southern Delta, SOR is a tidally influenced waterway affected by multiple saline discharges (DWR 2007). Although the discharges include point-source wastewater and non-point urban runoff, the majority are associated with drainage from agricultural lands surrounding SOR and its tributaries. A less verified source of salt loading appears to be groundwater effluence from the watershed south of SOR. Many of the sources have been monitored and exhibit conductivities ranging from 350 to 4,500 µS/cm with medians of 743 to 2,600 µS/cm. As water flows down SOR, salinity cumulatively increases from the incremental input of these sources located throughout the river's length. Increases can be further compounded by evaporation and agricultural diversions that remove water, reducing in-channel dilution capacity. The elevated salinities in discharges of agricultural and groundwater origin are due, in part, to the mineralized Diablo Range soils that make up the watershed's ancient alluvial fan.

Based on lithologic maps, much of the surface geology of the Diablo Range immediately up-gradient from the south Delta is classified as marine sedimentary rock (Davis 1961). Soils in the southernmost portion of the Delta originated, to varying degrees, from these marine deposits (DWR 1970). Resident soil south of SOR is characterized as water-laid sediment eroded from the Diablo Range, forming an alluvial fan sloping downward towards SOR. The alluvial fan contains an abundance of readily soluble minerals. The associated groundwater is more saline compared to groundwater from other locations around the Delta (Sorenson 1981). The heavily mineralized soils (and accompanying groundwater) provide one explanation for the elevated salinities in discharge and tributary inputs to SOR. Farther north, the soils transition to a less mineralized mixture of organic deposits, eroded Diablo Range material, and sediment from the Sierra Nevada flushed down into the floodplain during periods of heavy runoff.

Study Overview

To better characterize the water quality impacts from discharge and tributary inputs to SOR, surface-salinity transects were conducted throughout a major portion of the river over a two year period starting in January 2009 and continuing through most of 2010. The inputs to SOR identified in this study are described in the next section (Study Area). Boat transects were performed with a conductivity probe and logger merged with a GPS unit generating latitude-longitude coordinates. Transects typically started at the head of Middle River and ended near the approach channel to C.W. “Bill” Jones (Jones) Pumping Plant. Transects were also conducted over shorter stretches of SOR multiple times to capture specific input events induced by changing flow conditions during a tidal cycle. Further, several input sources (discharge or tributary) were periodically monitored for flow, conductivity, temperature, and turbidity.

Data were assessed in the “Results and Discussion” section following a detailed description of the materials and methods. Conductivity increased with distance downstream, reaching a peak near the western end of each transect run before declining from the influx of lower salinity water shifting up the river with tidal flow. The lower salinity water originates from flows moving north-to-south via cross-Delta waterways and/or Grant Line Canal drawn by south Delta export pumping (DWR 2004). Although all input sources identified in this study potentially contributed to the total SOR salt load, fewer than a dozen measurably influenced transect conductivity. The measured effects by one source or a combination of sources included isolated conductivity slugs/spikes, stepped increases, or gradually rising trends.

The compliance station at Tracy Boulevard Bridge was routinely impacted by inflows from Paradise Cut, a major tributary, and saline discharges from an agricultural drain located immediately upstream. The resulting effects of these two sources included wide-ranging conductivity fluctuations from slugs passing with bidirectional tidal flow or sustained increases due to the buildup of comingled saline inputs. The highest transect conductivities were usually detected farther downstream in western SOR largely due to the accumulation of multiple inputs from sources located both upstream and downstream of the compliance station. Overall, conductivity increased by 5% to 125% between initial and maximum levels before declining from dilution at the western transect boundary. Saline outflows from SOR were eventually intercepted by south Delta exports, terminating their continued migration into the Delta.

II. Study Area

South Old River (SOR) is a tidally influenced waterway located in the southern Sacramento-San Joaquin Delta (Delta), extending from the San Joaquin River to the approach channel to C.W. “Bill” Jones (Jones) Pumping Plant (formerly Tracy Pumping Plant) (Figure 1). Water from the San Joaquin River enters the head of Old River and flows west to the bifurcation with Doughty Cut (Figure 2). Doughty Cut conveys water northwest to Grant Line Canal (and Fabian and Bell Canal) with the remainder flowing down the SOR main stem. The transect route encompassed a portion of SOR from the head of Middle River to the western boundary (Figure 2).

South Old River and its tributaries are the receiving waters for a variety of discharges, most of which originate as drainage from agricultural lands. The discharge and tributary inputs to SOR are shown in Figure 2 and detailed in Tables 1 and 2. Twenty-nine discharge structures are situated on SOR and another 21 on the tributaries Tom Paine Slough and Wicklund, Sugar,

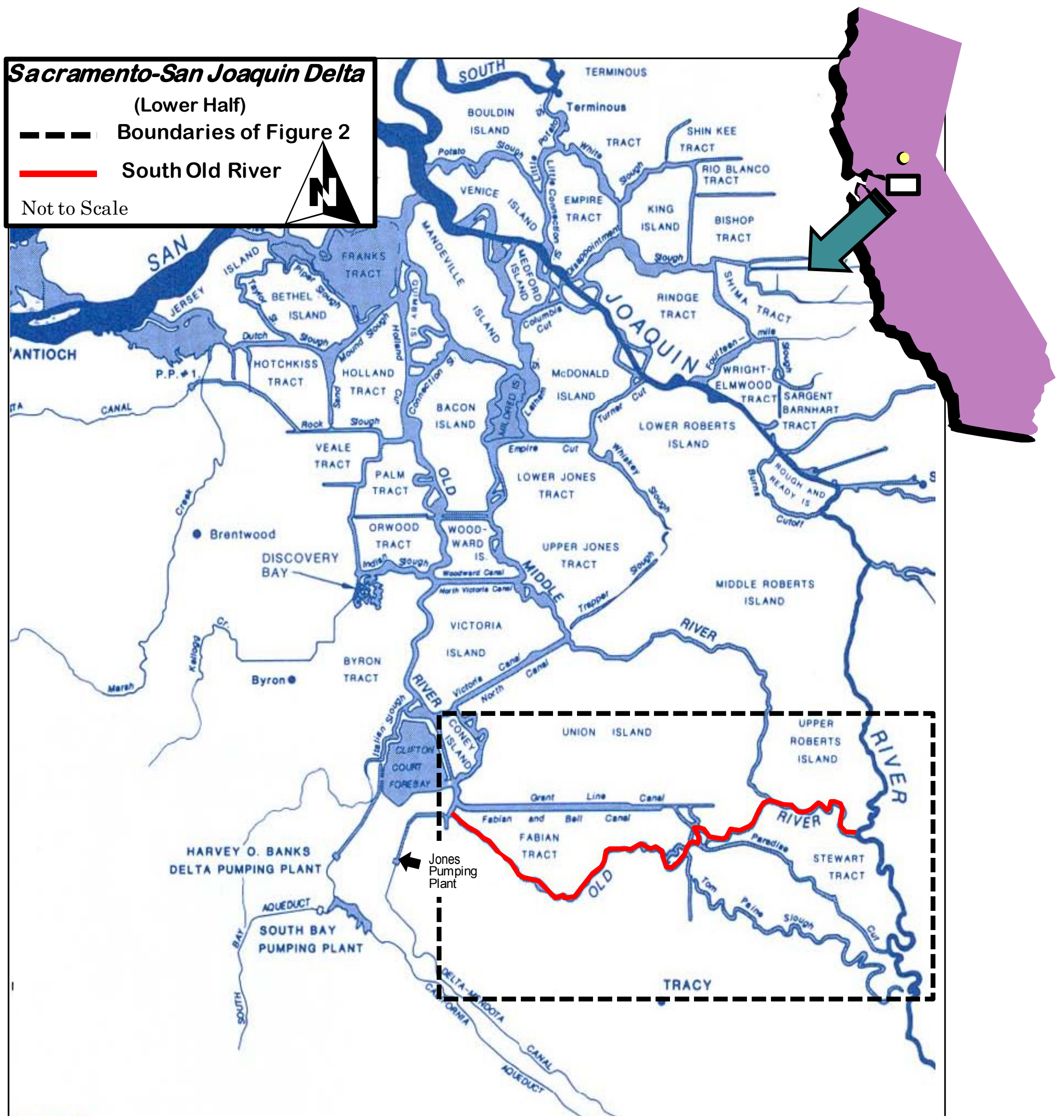

Figure 1. Location of South Old River in the Sacramento-San Joaquin Delta

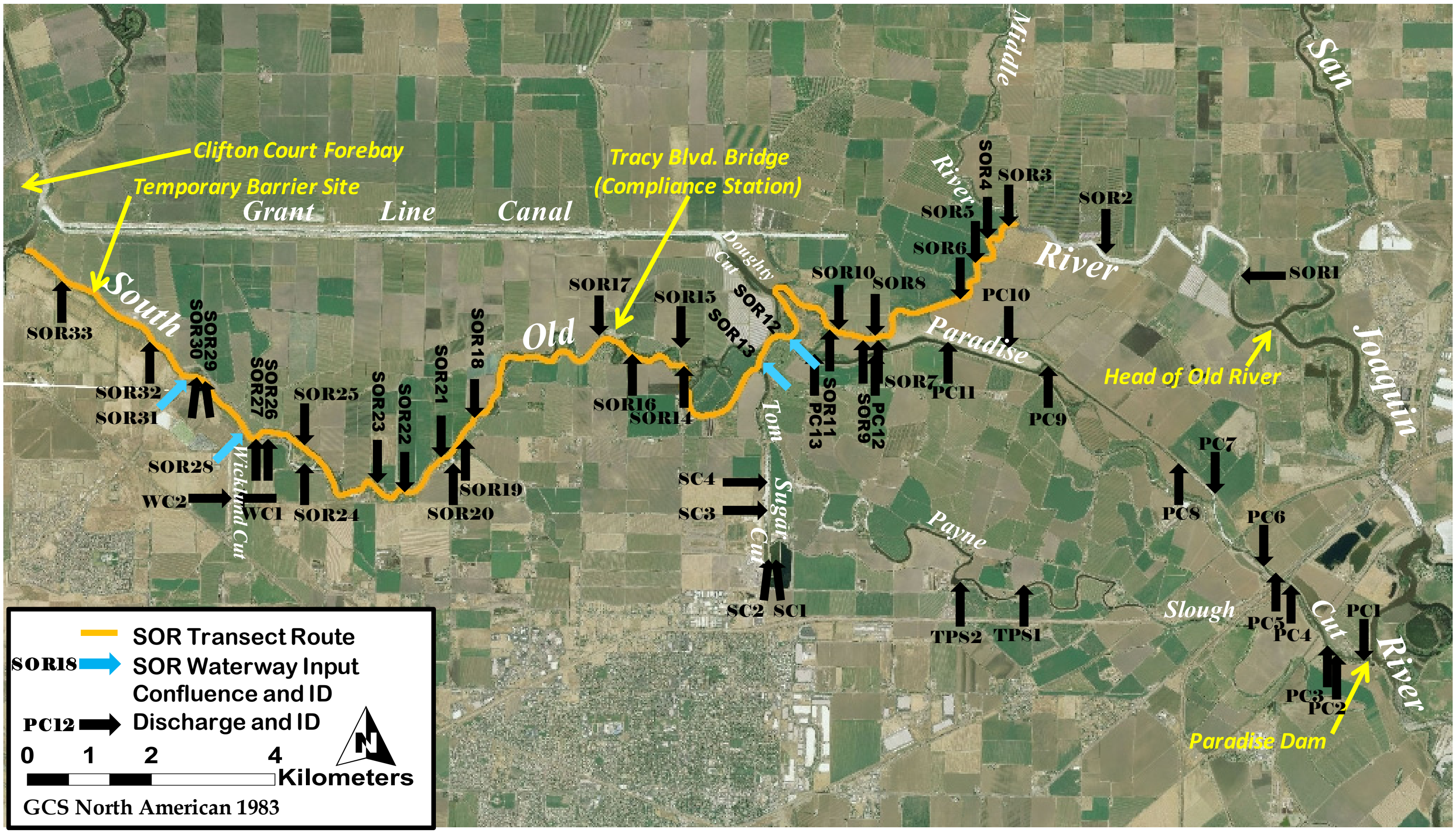

Figure 2. South Old River transect route along with discharge and tributary inputs (inset map shown in Figure 1). Discharge and tributary inputs are detailed in Tables 1 and 2.

and Paradise Cuts. Most discharge structures consist of one pump or a cluster of several pumps located on the landward side that force water from agricultural collector drains over the levees in one or more pipelines. Discharge structures also consist of pipes, ditches, or large channels where drainage and surface runoff is conveyed offsite.

Discharge pipelines along SOR and its tributaries were typically visible from the water side, extending from the levee crest to below the water. Notable exceptions included four that were discovered during transect runs when active discharges were visibly observed bubbling up from below the water's surface (see "Pipelines (concealed)" in Table 1). These pipelines were either plumbed through the base of the levee or hidden by foliage. Three discharges were located off the main SOR channel along secondary meanders or shallow oxbow curves (SOR15, SOR20, and SOR24, Figure 2). Some of the discharge pipelines listed in Tables 1 and 2 may be abandoned or attached to inactive pumping installations like the one on Paradise Cut (PC2). All pipelines were not investigated for active/inactive status due to access or private property restrictions. Several of the identified inputs were locations where drainage flows by gravity to SOR or its tributaries via corrugated pipes or open channels (WC1, WC2, SC1, and TPS1). Four ditches or pipelines were input points for runoff from agricultural lands within the floodplain (SOR11, PC5, PC8, and PC9).

Table 1. Discharge and tributary inputs to South Old River. Linear Referenced Meter = the distance between the head of Middle River (eastern end of transect, meter zero) and the approach channel to Jones Pumping Plant (western end of transect). Linear Referenced Meter is further defined in the next section.

Linear Referenced Meter	Input Feature (N)	Input Label	Input I.D.	Bank	Latitude	Longitude	Input Description	Source Footnote
N.A.	Discharge Pipeline	Pipeline 1	SOR1	N	37.8149	-121.3342	A	1
N.A.	Discharge Pipeline	Pipeline 2	SOR2	N	37.8186	-121.3597	A	1
76	Discharge Pipeline	Pipeline 3	SOR3	N	37.8221	-121.3759	A	1
603	Discharge Pipeline	Pipeline 4	SOR4	N	37.8195	-121.3800	A	1
1,068	Discharge Pipeline	Pipeline 5 (concealed)	SOR5	N	37.8168	-121.3816	A	1
1,924	Discharge Pipeline	Pipeline 6	SOR6	N	37.8111	-121.3855	A	1
3,658	Discharge Pipeline	Subsurface Wastewater Outfall	SOR7	S	37.8050	-121.4010	TSW	2
3,679	Discharge Pipeline	Pipeline 8	SOR8	N	37.8053	-121.4013	A	1
3,806	Discharge Pipeline	Pipeline 9	SOR9	S	37.8054	-121.4027	A	1
4,128	Discharge Pipeline	Pipeline 10	SOR10	N	37.8060	-121.4063	A	1
4,215	Drainage Ditch	Surface Drain	SOR11	S	37.8060	-121.4074	A	1
6,400	Tributary	Paradise Cut	SOR12	S	37.8054	-121.4157	A, GWE, TSW	3
7,241	Tributary	Tom Paine Sl./Sugar Cut	SOR13	S	37.8010	-121.4219	A, UR, GWE	4
9,371	Discharge Pipeline	Pipeline 11	SOR14	S	37.8001	-121.4348	A	1
9,785	Discharge Pipeline	Pipeline 12 (concealed)	SOR15	N	37.8034	-121.4364	A	1
10,450	Discharge Pipelines (3)	Tracy Blvd. Bridge Drain	SOR16	S	37.8026	-121.4452	A, GWE	5
11,016	Discharge Pipeline	Pipeline 14 (concealed)	SOR17	N	37.8043	-121.4506	A	1
13,889	Discharge Pipeline	Pipeline 15	SOR18	N	37.7935	-121.4726	A	1
14,424	Discharge Pipeline	Pipeline 16	SOR19	S	37.7895	-121.4759	A	1
14,724	Discharge Pipeline	Lammers Rd. Drain	SOR20	S	37.7863	-121.4772	UR	6
14,936	Discharge Pipeline	Pipeline 18	SOR21	N	37.7862	-121.4799	A	1
15,715	Discharge Pipeline	Pipeline 19 (concealed)	SOR22	N	37.7825	-121.4862	A	1
16,371	Discharge Pipeline	Pipeline 20	SOR23	N	37.7836	-121.4920	A	1
17,747	Discharge Pipeline	Bethany Rd. Drain	SOR24	S	37.7853	-121.5046	A, GWE	5
17,975	Discharge Pipeline	Pipeline 22	SOR25	N	37.7887	-121.5047	A	1
18,810	Discharge Pipelines (3)	Pipeline 23	SOR26	S	37.7895	-121.5131	A	1
18,937	Discharge Pipeline	Pipeline 24	SOR27	S	37.7901	-121.5142	A	1
19,055	Tributary	Wicklund Cut	SOR28	S	37.7910	-121.5149	A, UR, GWE	4
20,036	Discharge Pipeline	Subsurface Wastewater Outfall	SOR29	S	37.7974	-121.5225	TSW	7
20,065	Discharge Pipeline	Pipeline 26	SOR30	S	37.7977	-121.5225	A	1
20,268	Tributary	Mountain House Crk.	SOR31	S	37.7983	-121.5246	UR, GWE, R	8
21,201	Discharge Pipeline	Pipeline 27	SOR32	S	37.8037	-121.5321	A	1
23,066	Discharge Pipeline	Pipeline 28	SOR33	S	37.8130	-121.5492	A	1

1/ Agricultural
2/ Treated sewage wastewater from the City of Tracy
3/ Agricultural, overflow from San Joaquin River during extreme flows, groundwater effluence, treated sewage wastewater from Deuel Vocational Institution
4/ Agricultural, urban runoff from the City of Tracy, groundwater effluence
5/ Agricultural, groundwater effluence
6/ Urban runoff from the City of Tracy, other? (agricultural, groundwater effluence)
7/ Treated sewage wastewater from the Community of Mountain House
8/ Urban runoff from the Community of Mountain House, groundwater effluence, runoff from grazing and undeveloped land

Sources not associated with agricultural activities include groundwater, point-source wastewater, and urban or natural runoff. Treated municipal wastewater is discharged to SOR by the City of Tracy (SOR7) and the Community of Mountain House (SOR29) via diffusers situated across the riverbed. Deuel Vocational Institution's treated municipal wastewater enters an agricultural drain that empties into Paradise Cut (PC3). Groundwater is considered to be a component of waters entering SOR and its tributaries at several locations including SC1, WC1, SOR31, and possibly SOR20 and SOR28. Two of the sources associated with groundwater – SC1 and WC1 – are

Table 2. Discharges to South Old River tributary waterways

Waterway	Input Feature (N)	Input Label	Input I.D.	Bank	Latitude	Longitude	Input Source 1/
Paradise Cut	Discharge Pipeline	Pipeline 1	PC1	N	37.7605	-121.3096	SJR
	Discharge Pipeline 2/	Pipeline 2	PC2	S	37.7610	-121.3176	A
	Discharge Pipeline 3/	Pipeline 3	PC3	S	37.7616	-121.3179	A, TSW
	Discharge Pipeline	Pipeline 4	PC4	S	37.7678	-121.3228	A
	Drainage Ditch 4/	Surface Drain 1	PC5	S	37.7716	-121.3274	A
	Discharge Pipeline	Pipeline 5	PC6	N	37.7843	-121.3393	A
	Discharge Pipeline	Pipeline 6	PC7	N	37.7739	-121.3302	A
	Drainage Ditch 5/	Surface Drain 2	PC8	S	37.7874	-121.3447	A
	Discharge Pipeline 6/	Pipeline 7	PC9	S	37.8016	-121.3697	A
	Discharge Pipeline 7/	Pipeline 8	PC10	N	37.8045	-121.3799	A
	Discharge Pipelines (2)	Pipeline 9	PC11	S	37.8043	-121.3862	A
	Discharge Pipeline	Pipeline 10	PC12	S	37.8026	-121.4022	A
	Discharge Pipeline	Pipeline 11	PC13	S	37.8021	-121.4110	A
Tom Paine Slough	Open Channel	Surface Drain	TPS1	S	37.7677	-121.3778	A
	Discharge Pipeline	Pipeline	TPS2	S	37.7700	-121.3860	A
Sugar Cut	Open Channel	Surface Drain	SC1	S	37.7726	-121.4195	A, GWE, UR
	Discharge Pipeline	Pipeline 1	SC2	S	37.7270	-121.4197	Unknown
	Discharge Pipeline	Pipeline 2	SC3	W	37.7796	-121.4201	A
	Discharge Pipeline	Pipeline 3	SC4	W	37.7849	-121.4201	A
Wicklund Cut	Open Channel	Surface Drain	WC1	E	37.7801	-121.5172	A, GWE, UR
	Discharge Pipeline	Pipeline	WC2	W	37.7801	-121.5175	A

1/ A=Agricultural, GWE=Groundwater Effluence, UR=Urban Runoff (City of Tracy), TSW=Treated Sewage Wastewater from Deuel Vocational Institution, SJR=San Joaquin River

2/ Abandonded agricultural discharge pump

3/ Abandonded discharge pipeline over levee, passive flow through pipeline at levee base

4/ Toe drain along Manthy Rd. draining a small parcel of floodplain

5/ Surface runoff from floodplain farmland

6/ Pipeline sticking out of center island bank, appears abandoned

7/ Pipeline on north unnavigable channel

open channels flowing continuously throughout the year. Both SC1 and WC1, as well as SOR20 and possibly SC2 and SOR24 can also contain urban runoff from the City of Tracy. Natural runoff, groundwater, and urban runoff from the watershed encompassing the residential Community of Mountain House can flow by gravity to SOR via Mountain House Creek (SOR31).

One of the longer tributaries to SOR is Paradise Cut which serves as an overflow bypass channel for the San Joaquin River. During high flow conditions in that river, Paradise Dam at the head of Paradise Cut is overtopped with the floodwaters continuing downstream to SOR. The Paradise Cut floodplain is bounded by levees and comprised of several conveyance and interconnecting channels of varying sizes. The main channel is approximately 12 kilometers long (~7.5 miles) from Paradise Dam to the intersection with SOR. Other than floodwaters from the San Joaquin River, sources of water to Paradise Cut are largely associated with agricultural irrigation activities and rainfall runoff from agricultural lands. In the upper reach of Paradise Cut, groundwater accretion is presumed based on geochemical associations between salty, perpetually ponded water against the southwest levee and elevated salinity in Paradise Cut not associated with any known discharge(s). The source water for one of the pumped discharges on Paradise

Cut is the San Joaquin River (PC1), evidently to augment irrigation supplies for the few diversions located along the waterway. Paradise Cut also receives treated municipal wastewater from Deuel Vocational Institution via an agricultural drain (PC3).

Wicklund Cut is an artificial, tidally-influenced waterway connecting SOR with a large pumped diversion (perhaps the largest along SOR) at the southernmost end. Sugar Cut is also an artificial waterway that diverges with Tom Paine Slough upstream from SOR. Sugar Cut is a receiving channel for several discharges including a large, perpetually flowing input source composed of agricultural drainage, urban runoff, and groundwater (SC1). Tom Paine Slough is a major tributary draining mostly agricultural land south of SOR. Siphons positioned on Tom Paine Slough at the convergence with Sugar Cut are equipped with unidirectional flap gates designed to keep water levels in the slough high for irrigation pumps. The siphons prevent outflow during the growing season when water levels in the south Delta can be inadequate for diverters. Gates are opened when the siphons are taken out of operation, allowing water to flow freely in and out of upper Tom Paine Slough with tide.

Approximately 72 agricultural irrigation diversion installations are situated on SOR and its tributaries (DWR 1995, Delta Atlas). Most diversions consist of one pump or a cluster of several pumps on the water side of the levee. One passive diversion is located on SOR consisting of operable gates within the tidal zone.

III. Materials and Methods

Surface-salinity transects were conducted throughout a major segment of South Old River (SOR) over a two-year period starting in January 2009 and continuing through 2010. Transects were performed by boat using a probe submerged to a depth of approximately 0.5 meter. Conductivity and temperature were measured with a YSI 600LS combination sensor coupled with a YSI 650 MDS handheld logger/display device. The probe and logger were merged with a Garman GPSmap 76CRx GPS navigation system generating latitude-longitude position coordinates. The coordinates were logged with the associated YSI 650 time stamp using a YSI cable attachment. The YSI 600LS combination sensor was indirectly calibrated with a field meter at the start of each transect run. Field conductivity and temperature measurements were made with a Myron L Company Ultrameter II. The meter was calibrated within a day of use with standards formulated by DWR's Bryte Chemical Laboratory (Bryte Lab).

Transect boundaries on SOR extended from the head of Middle River (meter zero) in the east to just before the approach channel to Jones Pumping Plant (Figure 2). Transects were initially conducted around the higher- or lower-high tide for consistency, but later in the study, transect runs occurred during a variety of tidal conditions. Surface-salinity transects were also performed by boat over a long stretch of Paradise Cut. These transects were always scheduled during higher tidal conditions due to shallow water levels in the upper reach. Approximately 3,962 meters of Paradise Cut was impassible by boat. Data from the endpoint of the boat transects (usually the railroad trestle between PC6 and PC7) to Paradise Dam were obtained from eight, somewhat evenly spaced field conductivity measurements within a day of the transects.

Initially, boat transect measurements were programmed to be logged every second, but the frequency was decreased due to the generation of replicate coordinate positions. Measurements for most transect runs were recorded every two seconds, equating to values logged every six meters based on a boat speed of three meters per second (6.7 miles per hour).

All SOR transect runs were linear referenced using ESRI ArcMap 9.3. Transect latitude and longitude coordinates were converted to individual distance measurements between the beginning and end of each run. Meter zero was located at the head of Middle River, the eastern transect boundary. A representative (referenced) run was assigned to be the standard for distance measurements from which all other runs were associated. The linear referencing tool in ArcMap assigned the closest perpendicular distance measurement of each run with the referenced meter. Discharge and tributary inputs were also assigned linear referenced locations with the same ArcMap tool. Due to the meter assignment technique, any influence from discharges located on secondary meander channels on transect salinity would register at a different linear referenced location – the upstream or downstream meander convergence with the main channel.

Five discharge or tributary inputs to SOR were periodically monitored during this study for flow, conductivity, temperature, and turbidity (SOR16, SOR24, SOR31, SC1, and WC1). Flows were measured with a YSI SonTek FlowTracker Handheld ADV (Acoustic Doppler Velocimeter). The manufacturer claims an accuracy of 0.003 feet per second. An example of flow measurement and quality control statistics is presented in Attachment A. Field turbidity was measured with a Hach 2100P portable nephelometer. The nephelometer was calibrated within a day of use with Hach's

STABLCAL formazine standards. Field conductivity and temperature measurements were made with a Myron L Company Ultrameter II. The meter was calibrated within a day of use with standards formulated by Bryte Lab.

Quality control samples for conductivity were sent to Bryte Lab for analysis. Grab samples were collected from meter zero during a majority of the SOR transect runs and from Paradise Cut when boat transects ended at the railroad trestle. Samples were also periodically collected from the five discharge or tributary inputs monitored during this study. Quality control results are presented in Attachment B. Certain samples were analyzed for major minerals.

Water quality sampling, preservation, transportation, and analytical protocols were followed as per USEPA 1983, *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 1995), and *Water Quality Field Manual for the State Water Project* (DWR 2006A). The specifics are briefly described here.

Water quality samples were collected with a plastic jug from 0.1 meter below the surface at all stations. Precautions were taken to eliminate sample contamination in the field including the use of a “clean” sampling box for storage and transport of items used in the collection and filtration process. Clean items included unused filter cartridges, empty sample bottles, and baggies. Sample filtration was performed in the field using a peristaltic pump and tubing composed of Masterflex platinum-cured polypropylene. One Geotech or Gelman 0.45 micron absolute filter capsule was used to process dissolved samples for each transect or drainage collection date.

Water quality samples were transported on ice to Bryte Lab within 24 hours of collection. Analytical work was performed using methods approved in USEPA 1983 or APHA et al. 1995 (see Appendix A in DWR 2009 for individual analytical methods). As required for the Environmental Laboratory Accreditation Program in California, Bryte Lab filed a Quality Assurance Plan with the California Department of Health Services (DWR 2006B). The plan covers items required by USEPA such as organization and responsibility, laboratory sample procedures and identification, analytical methods, internal quality controls, and corrective action. Internal quality control checks included duplicates, check standards, reference standards, and control charts.

IV. Results and Discussion

Surface-salinity transects conducted in South Old River (SOR) are presented by month in Figures 3 through 7. Conductivity is plotted against linear referenced meter, the distance from the eastern transect boundary at the head of Middle River (meter zero). Discharge and tributary inputs listed in Table 1 are identified with thin dashed vertical lines and selected associated labels. The Tracy Boulevard Bridge compliance station position is designated by a solid vertical black line and the temporary barrier installation site is identified with a heavy dashed vertical black line.

Tidal stage from the station located on SOR at Tracy Boulevard Bridge (DWR California Data Exchange Center [CDEC] station identifier OLD) is shown in Figure 8 along with stage during each transect period. Figure 8 also shows when the SOR temporary barrier had been closed during installation and breached before removal.

A number of conductivity peaks and troughs were encountered throughout SOR during each transect run; some were consistent between runs but many were not. In general, conductivity increased with distance downstream, reaching a maximum near the western end of each run before declining from the influx of lower salinity water shifting up the river with tidal flow. The lower salinity water originates from flows moving north-to-south via cross-Delta waterways and/or Grant Line Canal drawn by south Delta export pumping (DWR 2004). Although

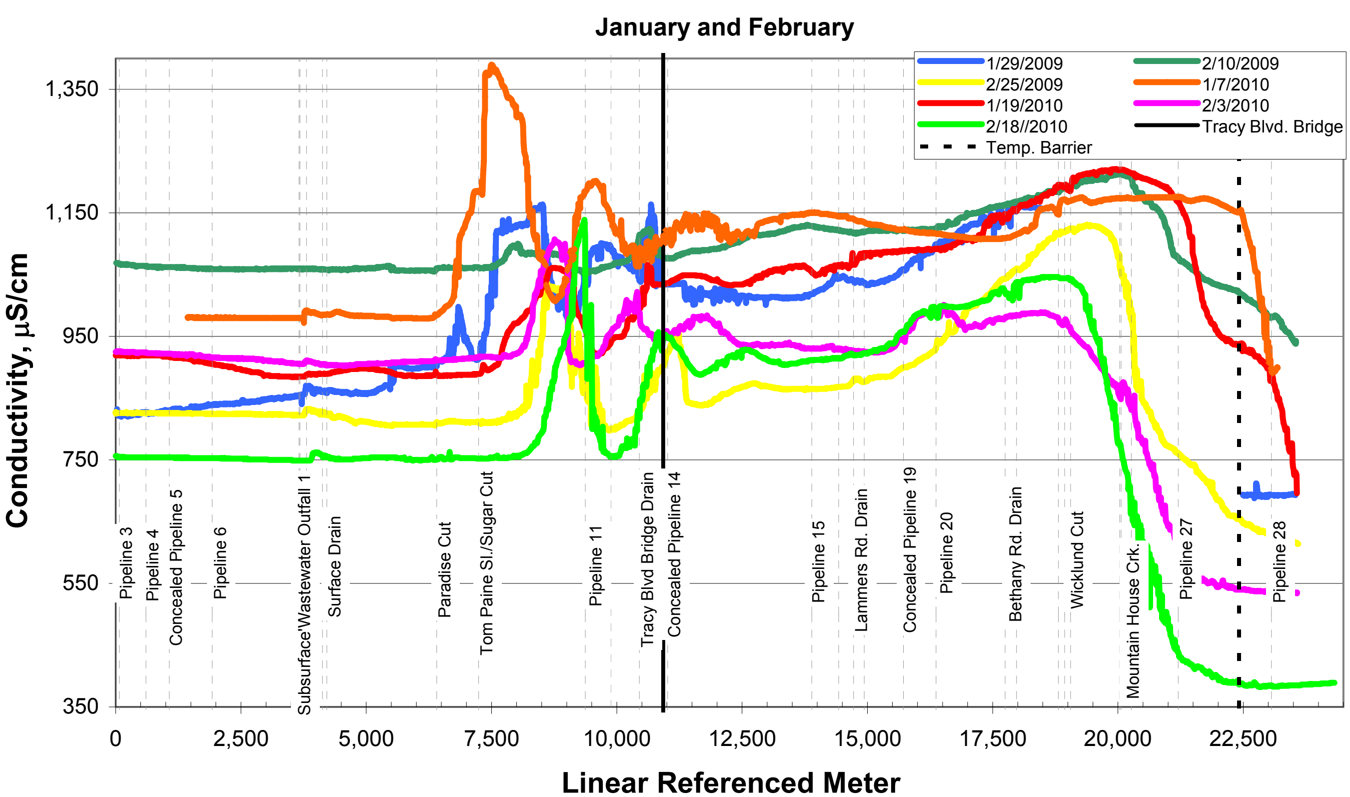

Figure 3. South Old River transects conducted during January and February

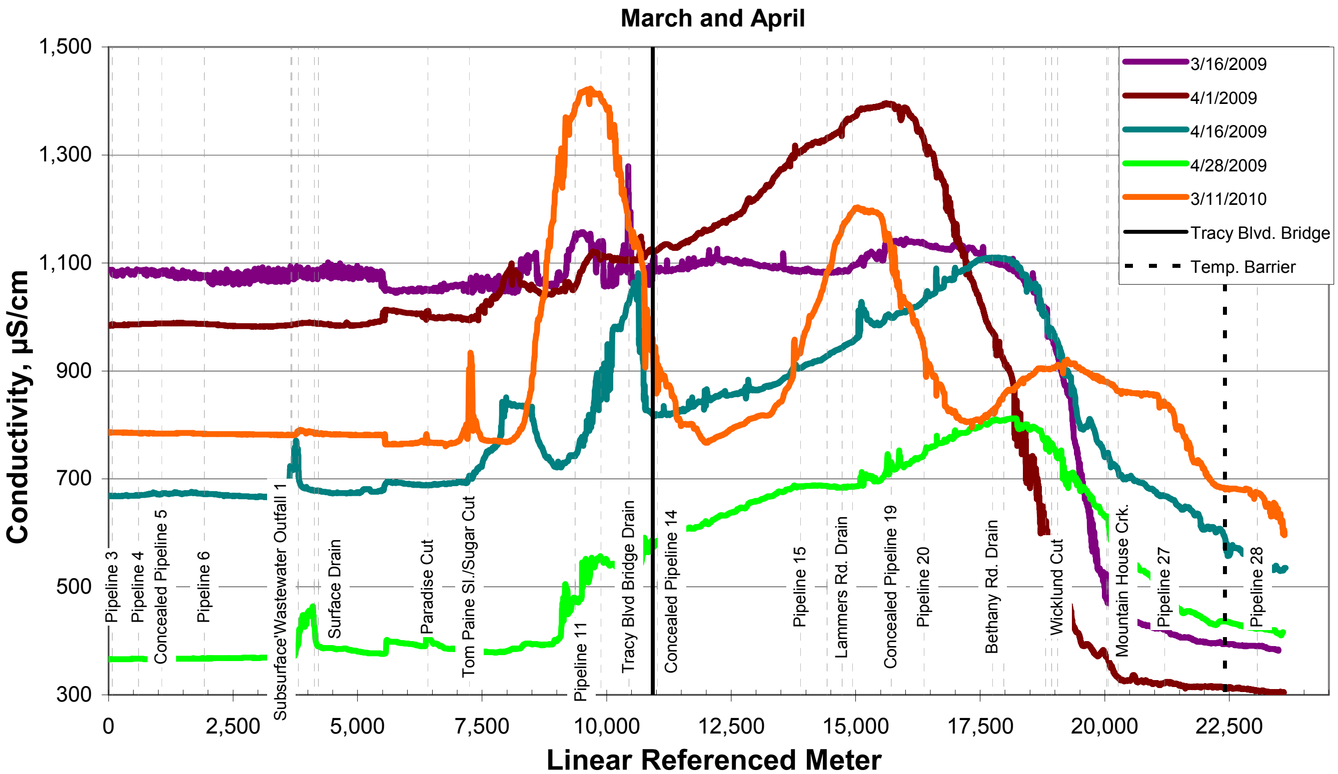

Figure 4. South Old River transects conducted during March and April

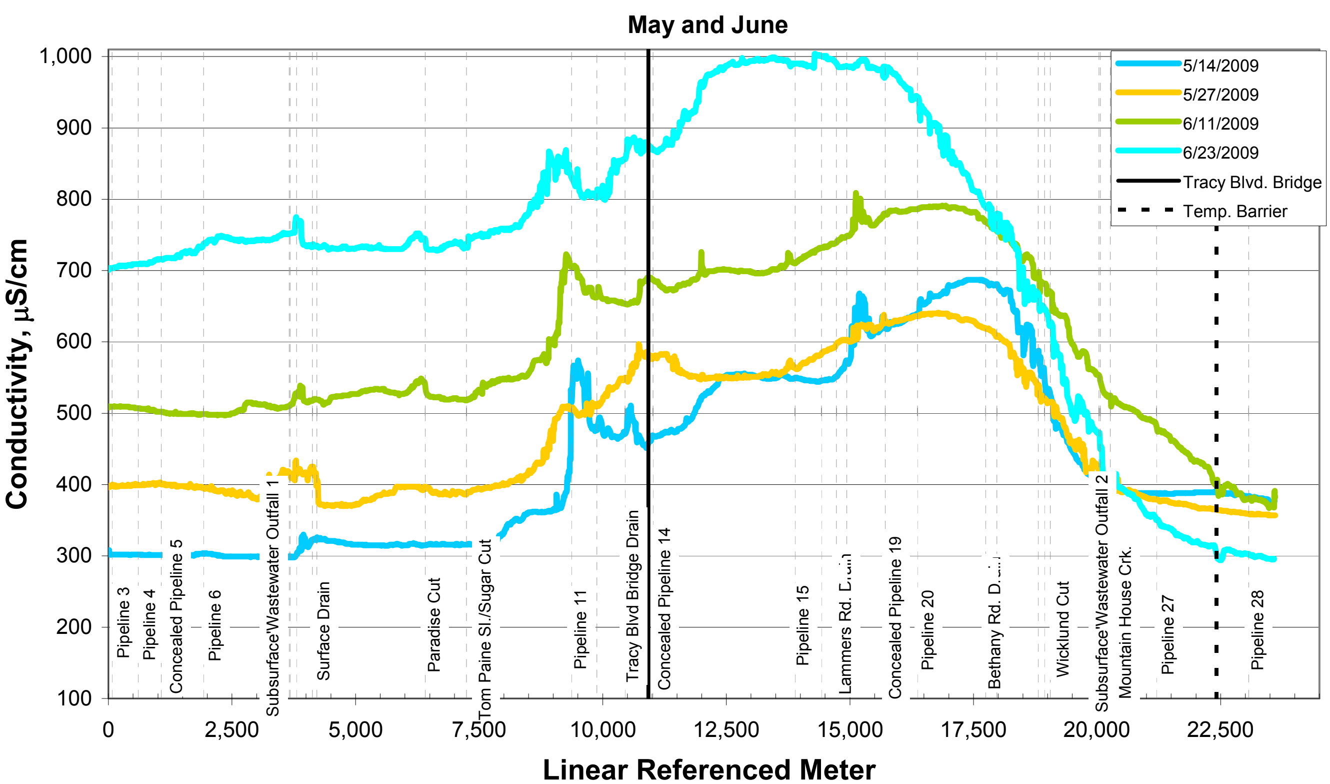

Figure 5. South Old River transects conducted during May and June

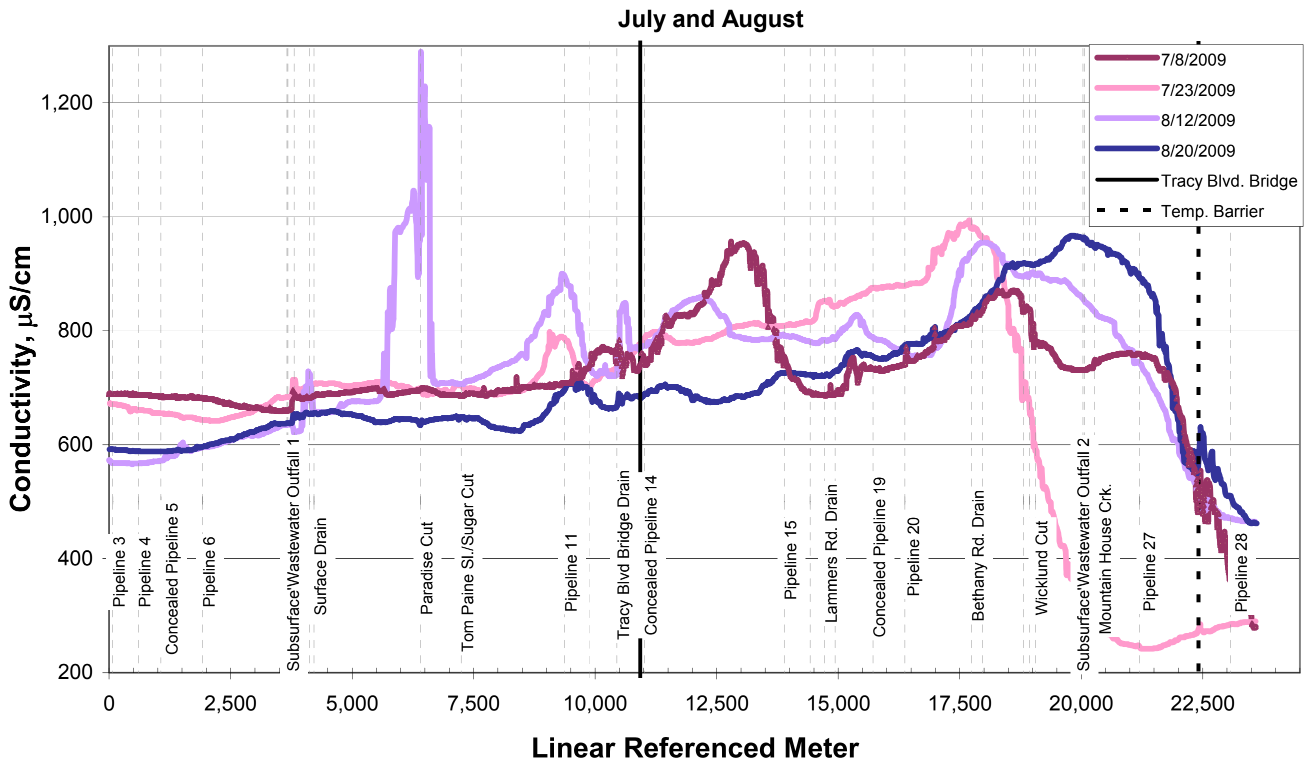

Figure 6. South Old River transects conducted during July and August

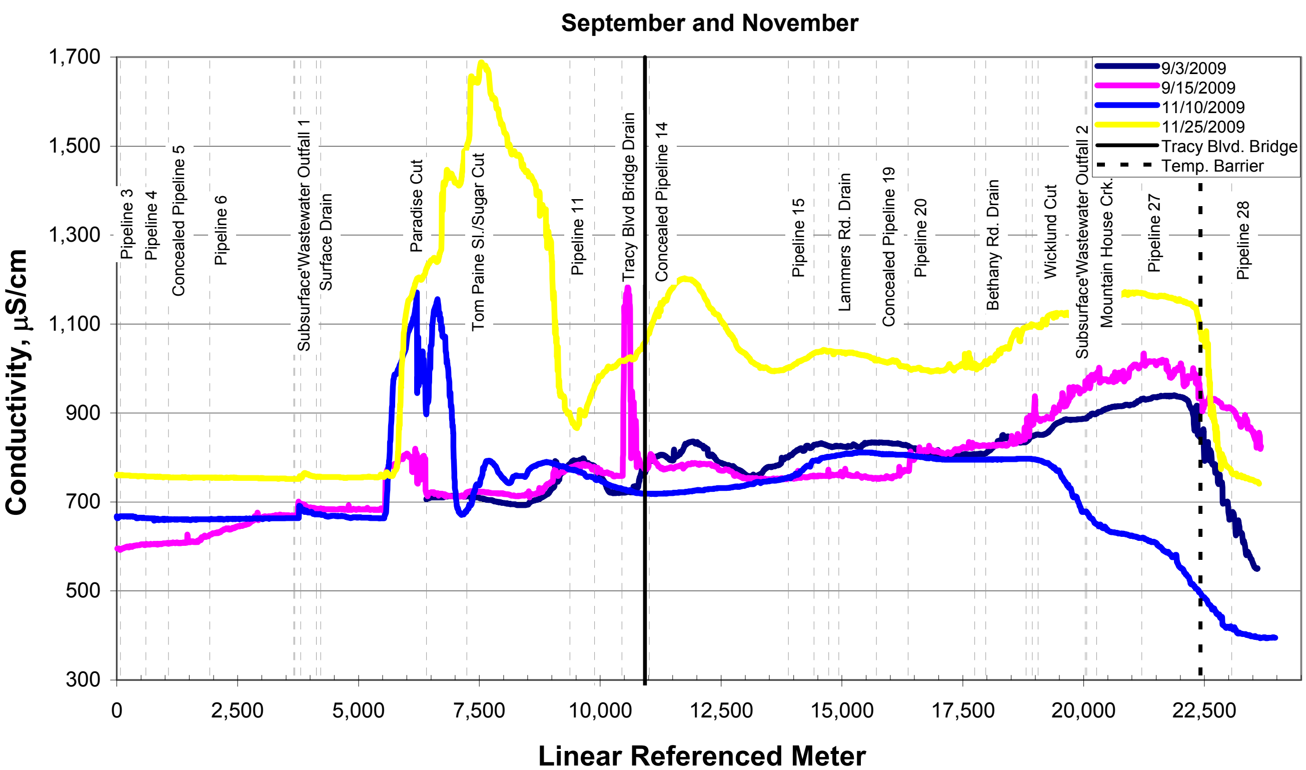

Figure 7. South Old River transects conducted during September and November

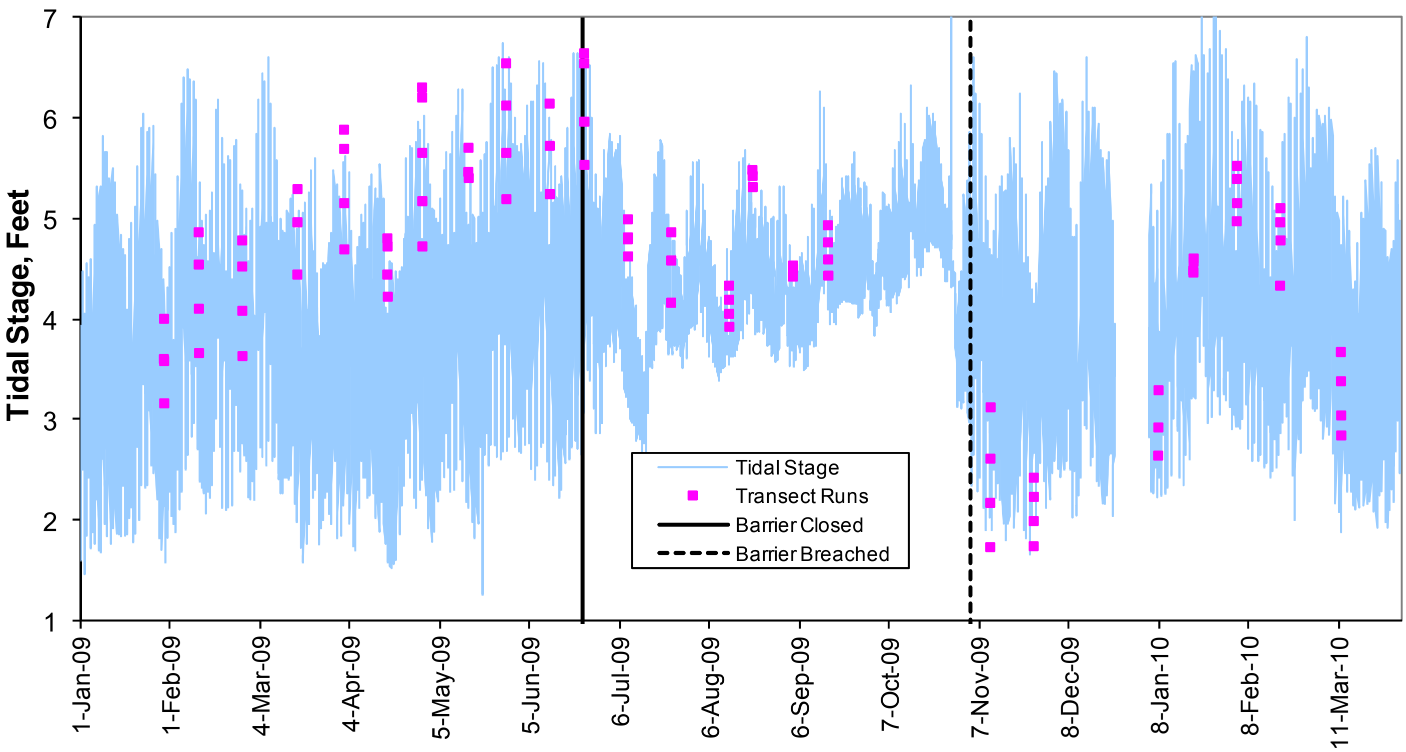

Figure 8. Tidal stage in South Old River at Tracy Boulevard Bridge (DWR California Data Exchange Center [CDEC] station OLD) with transect periods highlighted. Dates when the South Old River temporary barrier had been closed and breached are shown as vertical lines. Similar dates for barriers on Grant Line Canal were from July 1, 2009 to October 30, 2009.

numerous input sources (discharges and tributary waterways) identified in this study potentially contributed to SOR's overall salt load, fewer than a dozen measurably affected transect salinity. The measured effects by one or more sources included isolated conductivity slugs/spikes, stepped increases, or gradually rising trends.

Salinity trends and sources are discussed by multi-meter increments starting at the head of Middle River (meter zero). The distance from meter zero to the head of Old River upstream is about 6,700 meters. This stretch was not included in the transects due a reduced potential for effects from the higher dilution capacity upstream of the Middle River bifurcation.

Meters 0 to 5,000

One trend that was observed during most transect runs was a temporary uptick in conductivity between meters 3,000 and 4,500 (various transects in Figures 3 to 7). This trend occurred around the location of five discharge sources, the most notable being the City of Tracy's treated municipal wastewater effluent (meter 3,658). The upticks sometimes resulted in slight sustained increases. For instance, on May 14, 2009, conductivity increased from 300 to 325 µS/cm then leveled off at 316 µS/cm (Figure 5). Although the increase was relatively small, flows in SOR prior to the bifurcation with Doughty Cut at meter 5,550 provide a greater capacity for dilution compared to further downstream after the bifurcation.

Responsibility for these trends cannot be definitively assigned from this data due to the close proximity of multiple sources. However, the City of Tracy's wastewater discharge is the most probable entity. The discharge permit states a design flow of nine million gallons per day (~13.9 cfs) and a salt content of 1,753 µS/cm (highest annual average) (CVRWQCB 2011). Two input sources co-located in the vicinity are simply sites where runoff from agricultural land within the SOR floodplain is routed to the river (ditch and corrugated pipe). The other two nearby agricultural discharges are pipelines plumbed over the north levee.

Meters 5,001 to 10,000

Paradise Cut

The most pronounced isolated conductivity slugs were detected between meters 5,001 and 10,000, including those revealed during transect runs on January 7, 2010 (Figure 3), March 11, 2010 (Figure 4), August 12, 2009 (Figure 6), and November 25, 2009 (Figure 7). During this last run, conductivity increased from 758 µS/cm at meter 5,694 to a peak of 1,688 µS/cm near meter 7,540, a rise of 930 µS/cm (123%) over a distance of 1,846 meters. Another large isolated slug, detected in the same vicinity on August 12, 2009, appeared to be in the early phase of formation. Conductivity went from 677 µS/cm to a peak of 1,290 µS/cm over a distance of 900 meters and then declined to 711 µS/cm after 250 meters (Figure 6). The relatively rapid rise and fall in conductivity suggests the source was directly adjacent to the crest – the Paradise Cut tributary at meter 6,400. Supporting evidence included wide oscillations at the confluence implying the probe was passing in and out of plumes of high salinity water emanating from the source. The slug was detected seven hours after a higher-high tide suggesting formation with tidal outflow.

To capture Paradise Cut outflows under changing tidal conditions, multiple transects were conducted over a short segment of SOR on July 20, 2010. The abridged transects began near the bifurcation with Doughty Cut (meter 5,550) and ended just past the confluence with Tom Paine Slough (Figure 9). Conductivity during the first transect run remained unchanged past the mouth of Paradise Cut (extending between meters 6,341 and 6,425) (Figure 10). Tidal stage at the Tom Paine Slough gauging station was four hours past a higher-high or 4.91 feet (Figure 11). Conductivity at the start of the second run was 105 µS/cm higher and continued to rise until the confluence with Paradise Cut where it declined sharply. Run three revealed a newly formed slug moving downstream with a crest positioned at meter 6,530 (tidal stage = 3.95 feet) almost seven hours after the first run.

The abridged transects show that saline water from Paradise Cut had been drawn into SOR sometime after the first run and moved upstream. This was evident on the second run whereby conductivity increased approaching Paradise Cut from upstream followed by an abrupt decline at the confluence. Approximately five hours had elapsed between runs one and two. Although tide was falling, the net hydrological draw at that particular stretch of SOR was towards Doughty

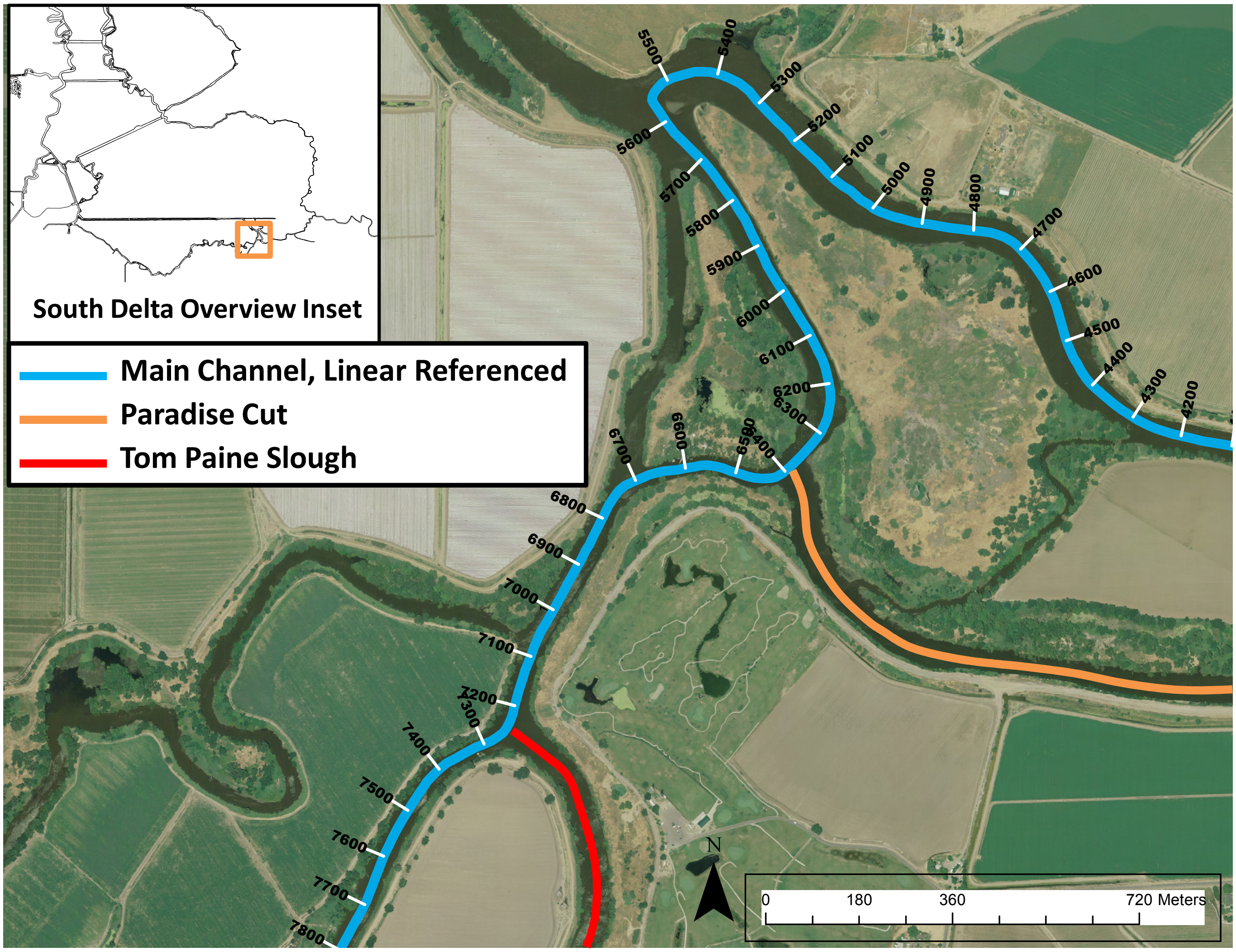

Figure 9. South Old River near the tributaries Paradise Cut and Tom Paine Slough. The linear referenced values are in meters.

Cut, not down the main channel. Between the second and third runs (and just prior to a tidal trough) flow reversed and carried the newly formed slug in the opposite direction – downstream. The time between runs two and three was a little over two hours. Therefore, it took at most a total of seven hours for a slug to form, initially migrate upstream and then begin moving downstream. The wide oscillations on the second and third runs indicate plumes of higher salinity water from Paradise Cut continuing to mix with lower salinity water in the main channel.

The abridged transects provide an explanation for aspects of the conductivity slug observed around meter 6,400 during the August 12, 2009, transect (Figure 6). The slug was positioned just upstream from Paradise Cut on a declining tide – comparable to the circumstances associated with the second run in Figure 10. The same trend was evident during the run on September 15, 2009 (Figure 7). In all examples, the conductivity slug was in the initial phase of formation, positioned immediately upstream of Paradise Cut, and present well past a higher-high tide. The initial upstream movement of water from Paradise Cut with declining tide has the potential to

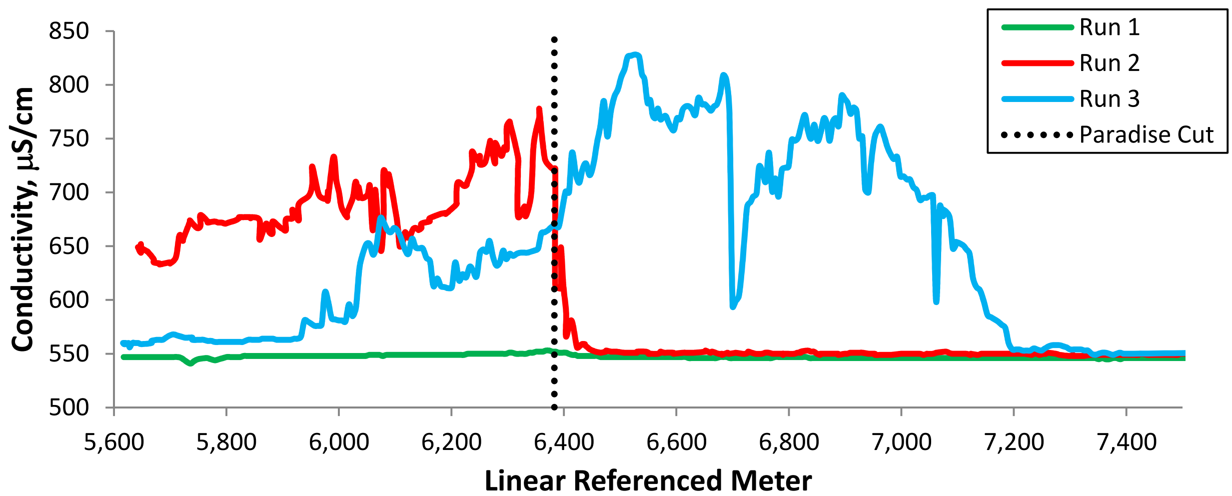

Figure 10. Multiple transect runs conducted in South Old River between meters 5,600 and 7,500 on July 20, 2010

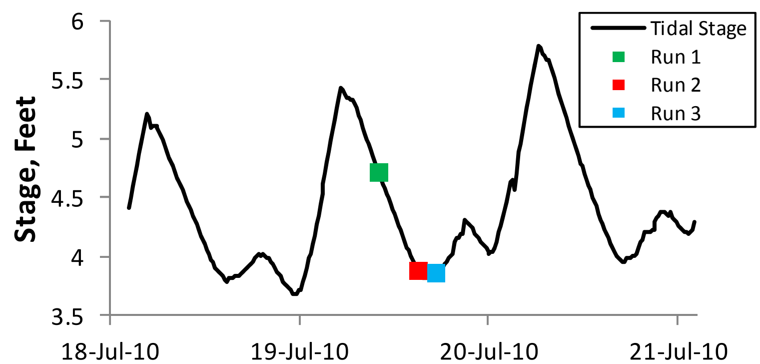

Figure 11. Tidal stage in Tom Paine Slough above the mouth (CDEC station TPS), July 18-21, 2010

influence salinity in Doughty Cut and eventually Grant Line Canal. Another consequence of this trend is the diversion of salt from Paradise Cut out of SOR.

Surface-salinity transects were conducted throughout Paradise Cut during the first year of the study. All transects were performed under higher tidal conditions due to shallow depths along the transect route that during lower tides prevented boat navigation. Boat navigation in the uppermost reach was not possible. Data from this 3,962 meter stretch of Paradise Cut culminating at Paradise Dam was obtained from field measurements collected at eight approximately evenly spaced locations within a day of each boat transect.

Conductivities immediately upstream from the confluence were comparable to those in SOR due to incoming tidal flow that forced river water up Paradise Cut (Figure 12). With the exception of one transect, the highest levels were measured between meters 7,000 and 9,500 (Figure 13) (note the February 25, 2009, transect was excluded because it was discontinued around meter 3,000 due to shallow water conditions). Surface runoff from the discharge sources situated along

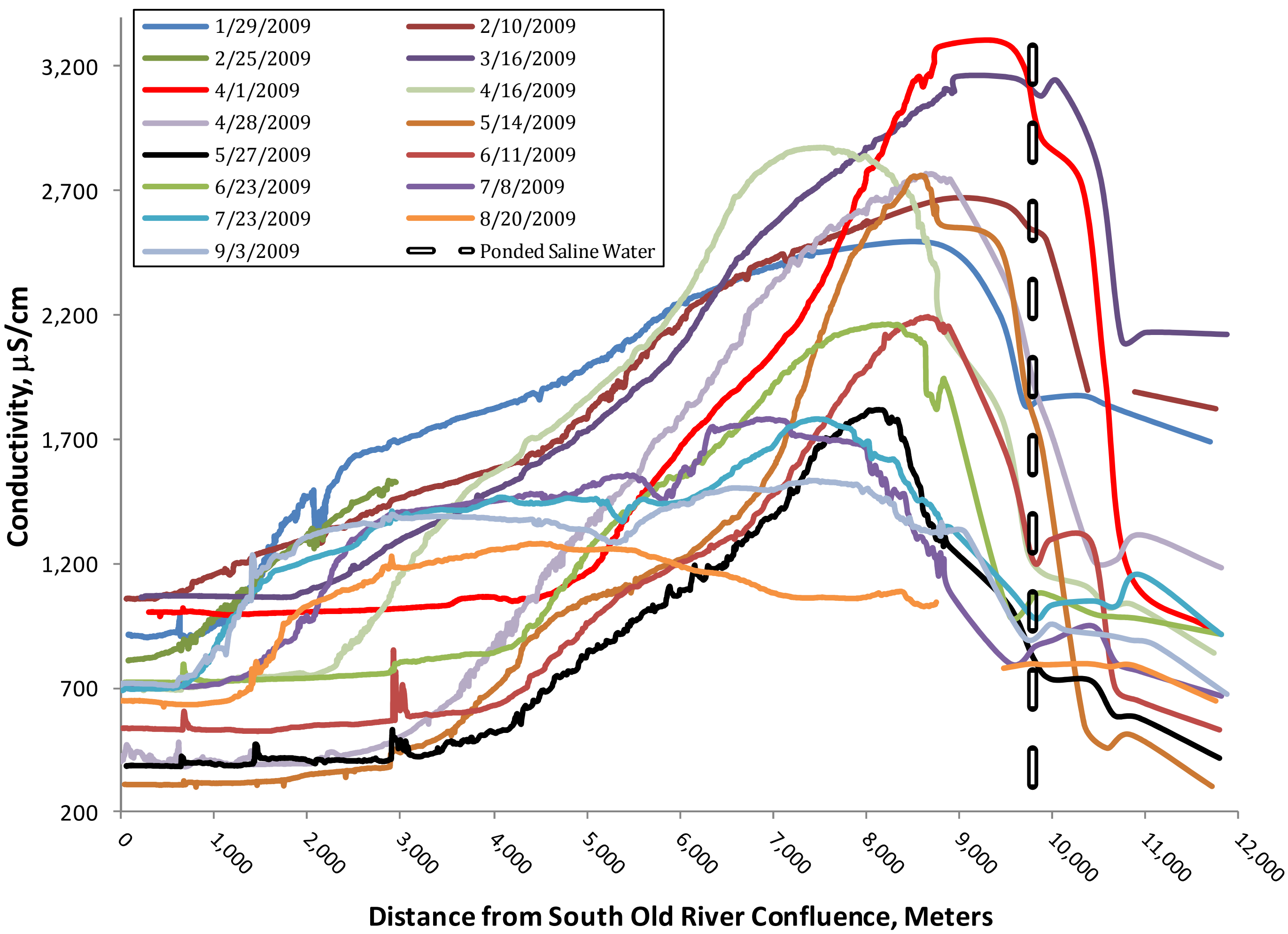

Figure 12. Surface-salinity transects on Paradise Cut from South Old River to Paradise Dam. Transects by boat were discontinued around meter 8,860 due to shallow depths. Data from that point to Paradise Dam originated from field measurements collected at eight somewhat evenly spaced locations within a day of the boat transects.

that stretch were not considered responsible for the elevated conductivities. One of the sources (PC8) is simply a location where runoff from cropland within the floodplain is conveyed offsite (Figure 13). Discharges from PC7 were never observed and PC6 is a surface drain for excess irrigation water (one conductivity measurement = 291 µS/cm). On the three occasions that discharges from PC4 were observed, conductivity ranged between 946 and 1,026 µS/cm.

One of the discharge sources shown in Figure 13 (PC5) is a dirt culvert at the base of a road embankment within the levee-bounded floodplain (this configuration may have changed over time from floodwater washouts and local grading activities). Although no surface discharges to Paradise Cut were observed from this source, perpetually ponded water within a short segment of the drain was highly saline. Located 66 meters from the main channel, conductivity of the drain water ranged from 2,007 to 7,304 µS/cm with a median of 5,535 µS/cm (n = 42). The presence of groundwater effluence in this drain provides an explanation for the elevated salinities

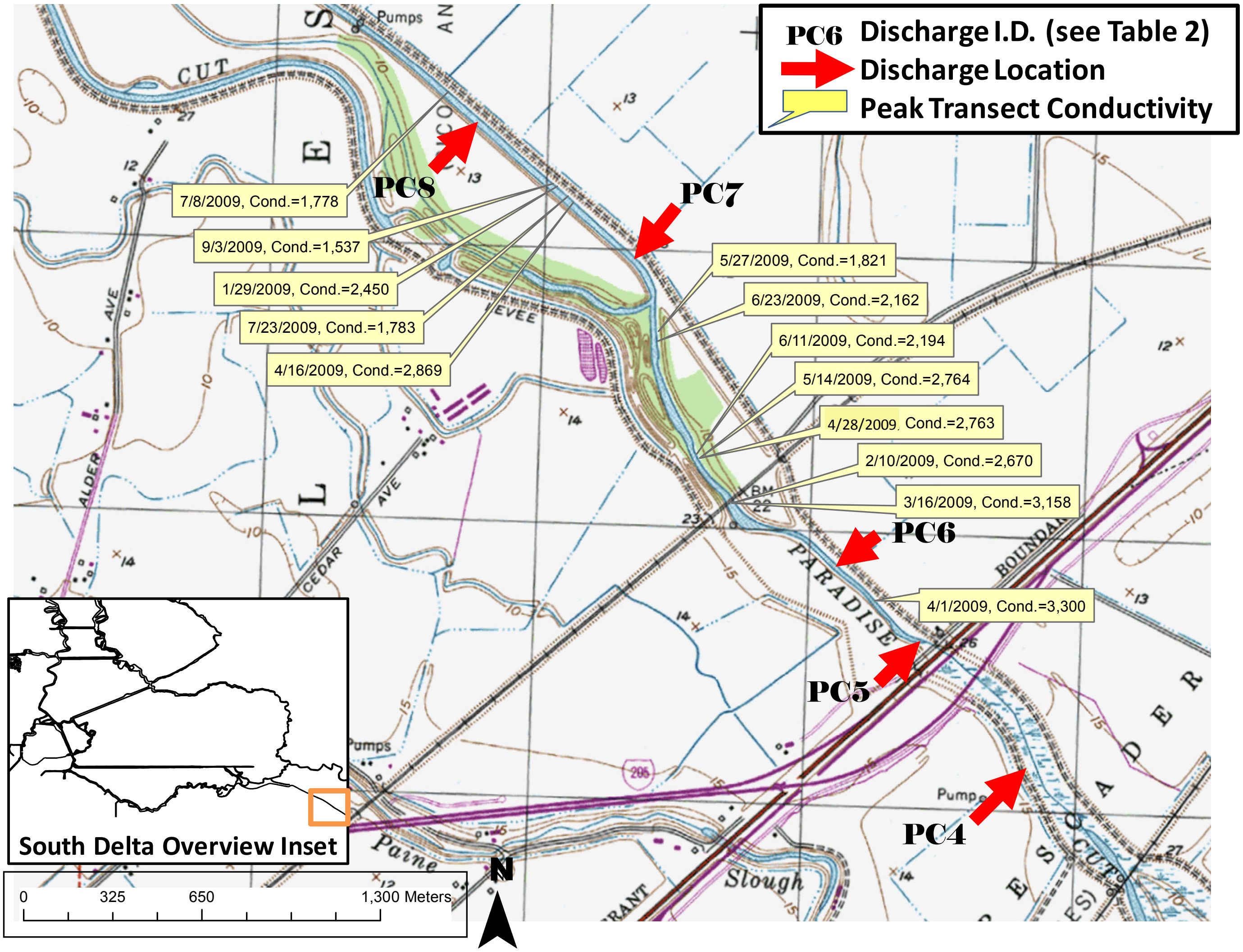

Figure 13. Location of peak transect conductivities (Cond. in μS/cm) in the upper reaches of Paradise Cut and nearby discharge sources

detected in upper Paradise Cut: Saline groundwater originating southwest of the channel was discharging to Paradise Cut. The location of PC5 with respect to transect conductivity is shown in Figure 12.

Influence from groundwater discharges on Paradise Cut salinity was supported by seasonal changes in peak conductivities. Conductivity between meters 7,000 and 9,500 was highest in transects from January to mid May. Peak values during those months ranged from 2,450 to 3,300 μS/cm (median = 2,764 μS/cm) versus a range of 1,276 to 2,194 μS/cm (median = 1,783 μS/cm) during the rest of the year (Figure 13). The period of highest salinity occurred when aquifer recharge is commonly greatest – winter and early spring (USGS 1983). Enhanced recharge rates lead to higher groundwater elevations with potential consequent increases in subsurface discharges. Peak transect conductivities in Paradise Cut were lowest later in the year (late May to early September) when recharge rates can decline. Visual observations of receding water levels in PC5 throughout the year provided substantiating evidence for a reduction in groundwater head due to seasonal recharge fluctuations.

A geochemical comparison between water ponded in PC5 and Paradise Cut corroborates groundwater influence. Ponded water quality was compared with a gradient of conductivity-associated mineral samples collected from Paradise Cut at the end of each boat transect run, usually near the railroad crossing at meter 8,860 where the field measurements began (Figure 13). The geochemistry of Paradise Cut approached that of PC5 with increasing conductivity (Figure 14). The tendency was strongest for anions: the anionic composition of PC5 was nearly identical to that of Paradise Cut in the highest conductivity range. Both waters exhibited an anionic composition dominated by chloride whereas samples collected from SOR at Tracy Boulevard – presented for comparison – exhibited compositions more inclusive of sulfate and bicarbonate. This evidence further demonstrates a groundwater component augmenting Paradise Cut salinity by varying degrees throughout the year. The groundwater discharges, in conjunction with numerous agricultural inputs along the waterway, eventually influenced conductivity trends in SOR during periods of tidal outflow.

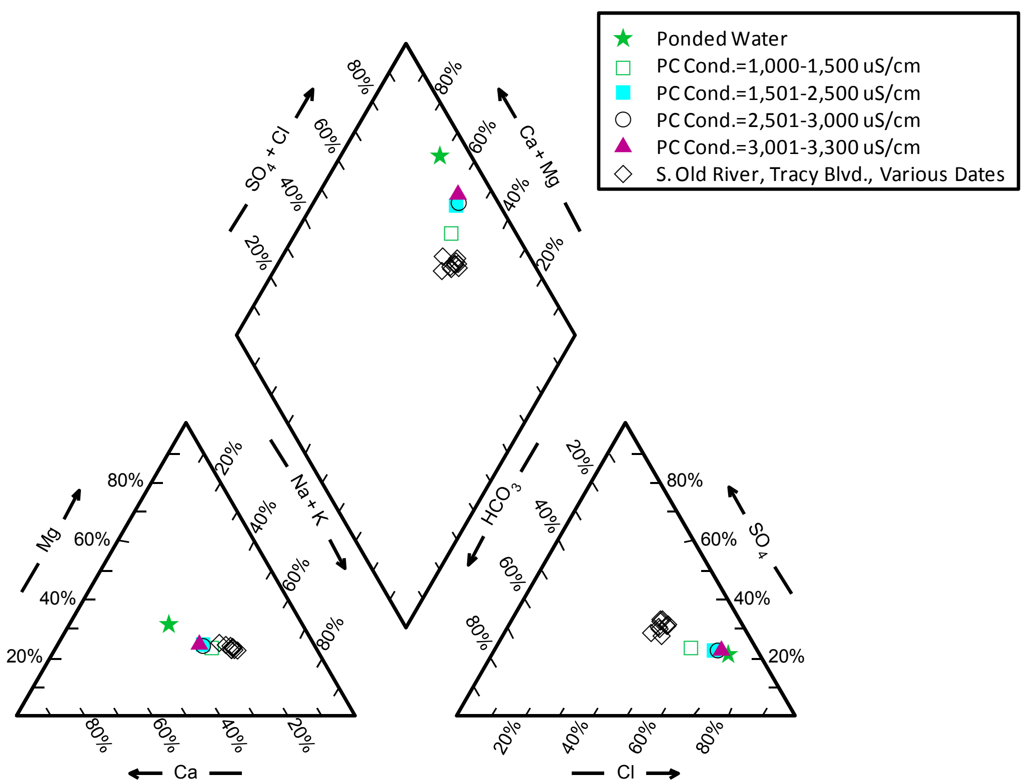

Figure 14. Piper graph of saline ponded water in PC5 versus Paradise Cut (PC) near meter 8,860. Paradise Cut data was segregated by conductivity (Cond.) range.

Presumably, the most pronounced isolated conductivity slugs in SOR downstream of Paradise Cut originated from this tributary. The large size and numerous discharges situated throughout its length make it an obvious source for substantial inflows and corresponding salt loads to SOR. The Paradise Cut watercourse extends almost 12 kilometers (~7.5 miles) from the confluence to Paradise Dam and receives agricultural drainage from 11 known sources, treated municipal wastewater, and subsurface groundwater inflows. The excursion profile characteristics of some of the largest SOR slugs in Figures 3 to 7 relative to their distance from Paradise Cut implicate this waterway as the most likely candidate.

During the transect on March 11, 2010, two large isolated conductivity slugs were detected 5,436 meters apart (Figure 4). The crests were positioned 3,208 and 8,644 meters downstream from Paradise Cut and both exhibited relatively decayed excursion profiles. Decayed excursion profiles are usually characterized by smooth rising/recession limbs with shallower slopes indicating they were not recently generated. In contrast, profiles of the large isolated slugs detected almost 1,000 meters downstream from Paradise Cut during transects on January 7, 2010, and November 25, 2009, were less decayed, exhibiting steeper and more uneven excursion limbs (Figures 3 and 7). The shorter downstream distance is consistent with their younger or less decayed profiles. They had been subjected to fewer dispersing tidal cycles than the pair of slugs detected during the March 11, 2010, transect. The abridged transects, features (length, plentiful sources of salt), and excursion profile analysis provide ample evidence that this waterway is the source of some of the largest slugs flowing down SOR. As such, the expansive rise and fall in conductivity frequently observed at the Tracy Boulevard Bridge compliance station can, at times, be attributed to recurring, tidally-induced inflows from Paradise Cut.

Tom Paine Slough

Although Tom Paine Slough is another major tributary with a seeming potential for contributing to SOR salinity trends, evidence like that observed for Paradise Cut was limited. This was not unexpected since the waterway is equipped with unidirectional siphons upstream of SOR to accept tidal inflows and prevent outflows. The siphons are positioned at the intersection with Sugar Cut and are designed to keep water levels in the slough high for seasonal irrigation diversions. One set of abridged transects did show this waterway can sometimes be the source of tidally generated salinity slugs in SOR.

Multiple abridged transects were performed in SOR past Tom Paine Slough on November 4, 2010. The first run detected a slight uptick in conductivity at the waterway mouth (meter 7,241) one hour past a lower-high tide (Figures 15 and 16). The first run also exposed a large, relatively young isolated slug with a crest positioned farther downstream at meter 10,065. This isolated slug was followed by two heavily decayed peaks that had almost fully merged. The presence of the two heavily decayed peaks below Tracy Boulevard Bridge imply that portions of saline water had repeatedly emanated from Tom Paine Slough during previous tidal cycles, merging together into more uniform levels due to dispersion. During the second run, saline outflows began forming a slug at the mouth as tide continued declining. The second run also revealed the isolated slug had moved 950 meters downstream with a crest maximum that declined from 1,042 µS/cm on the first run to 989 µS/cm. The third run showed continued growth of a forming slug at the mouth 1¼ hours after the first run.

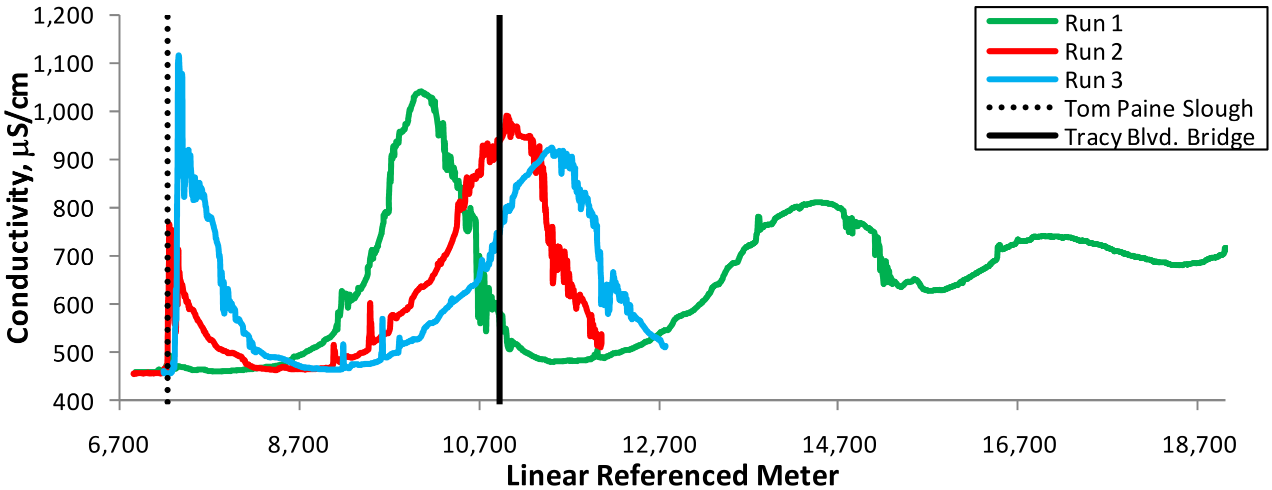

Figure 15. Multiple transect runs conducted in South Old River between meters 6,700 and 19,000 on November 4, 2010

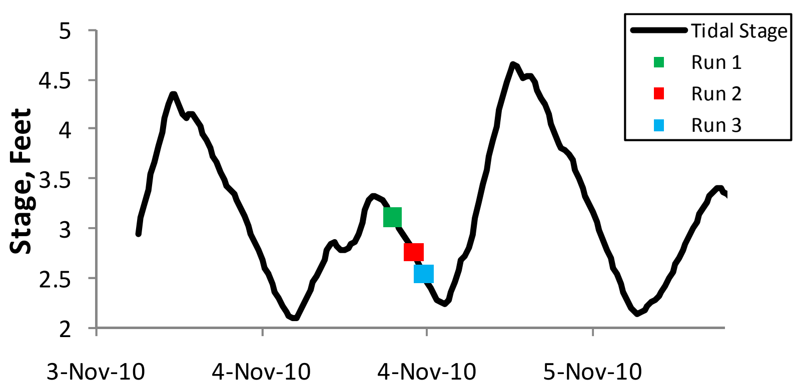

Figure 16. Tidal stage in Tom Paine Slough above the mouth (CDEC station TPS), November 3-5, 2010

Similar to trends observed at Paradise Cut, saline water from Tom Paine Slough was drawn into SOR with outgoing tidal flow. Unlike Paradise Cut, outflows did not initially shift upstream. The creation of downstream-migrating slugs from this waterway shown in Figure 15 may have been associated with siphon inactivation. Inactivation of the siphon on Tom Paine Slough due to the lack of irrigation needs at that time of year would have permitted water movement out of the slough. Siphon inactivation was supported with observations of depleted water levels in Tom Paine Slough (exposed banks and bed debris) upstream from the siphons during that month.

Sugar Cut

Sugar Cut is an artificial waterway that merges with Tom Paine Slough just downstream from the siphon location (1,216 meters upstream from SOR). Several discharges are situated along it including Arbor Road Drain which is an open channel with continuous flows entering at the southern end (SC1, Table 2 and Figure 2). Source waters to SC1 can include urban runoff from the City of Tracy, groundwater, and agricultural tailwater.

Flow and water quality in SC1 were periodically monitored during this study (Table 3 and Figure 17). Flow ranged from 0.9 to 51.4 cfs and exhibited a roughly increasing-to-decreasing trend between spring and early fall, although data was limited or nonexistent for some months. The peak flow of 51.4 cfs was measured during a winter storm event, reflecting a surge in urban runoff from the City of Tracy. Conductivity in SC1 ranged from 416 to 2,244 µS/cm with a median of 1,341 µS/cm. Conductivity was consistently lowest from May to September and displayed a somewhat inverse correlation with flow. The data imply that salinity declined due to irrigation activities during the growing season when flows increased. During winter and fall, conductivity reflected composition changes between low flow saline groundwater effluence versus short duration precipitation events generating high flow, low salinity rainfall runoff-dominated water. Although inflows from SC1 contribute to the overall salt load entering SOR, rainy season runoff events from the City of Tracy were shown to periodically produce high volumes of relatively low conductivity water (416 µS/cm at 51.4 cfs).

Table 3. Flow and water quality summary statistics for Arbor Road Drain (SC1) (Date range: January 2009 to December 2010)

Statistic	Flow (cfs)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Minimum	0.90	416	10.1	4.35
Maximum	51.4	2,226	29.5	186
Average	14.2	1,476	19.6	51.5
Median	15.2	1,341	19.8	42.5
Count (#)	28	88	86	79
Standard Deviation	10.9	440	4.34	42.4
Relative Percent SD (%)	76	30	22	82

Water temperature in SC1 ranged from 10 to 29.5 °C and was generally highest during the summer months (Table 3 and Figure 17). Turbidity was highly variable, ranging between 4.35 and 186 NTU with a relative percent standard deviation of 82%. This variability can be attributed to the diversity of source waters from low turbidity groundwater to sometimes highly turbid agricultural tailwater and urban runoff.

Discharges from SC1 must traverse the length of Sugar Cut and a portion of Tom Paine Slough before entering SOR. This distance totals 3,268 meters (2.03 miles) including 1,216 meters between the convergence with Tom Paine Slough and SOR. One transect of Sugar Cut on April 16, 2009, showed that salt contributions from SC1 and other potential discharges were heavily diluted during the traversal. Conductivity declined from almost 1,400 µS/cm in the upper reach to levels present in SOR (700 µS/cm) just downstream from the Tom Paine Slough siphon (Figure 18). Tidal encroachment of water from SOR up Tom Paine Slough had diluted the elevated salinities in upper Sugar Cut by half 1,100 meters upstream from the confluence.

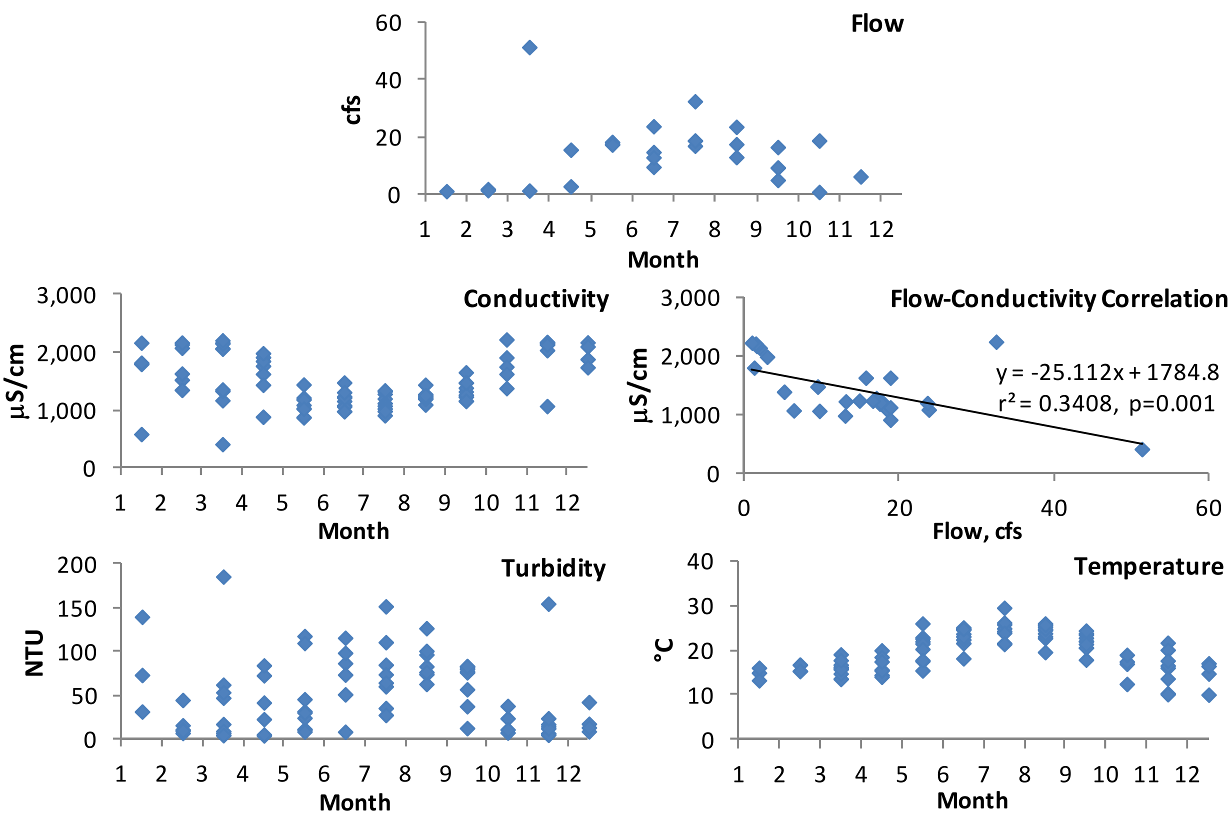

Figure 17. Seasonal flow and water quality trends for Arbor Road Drain (SC1)

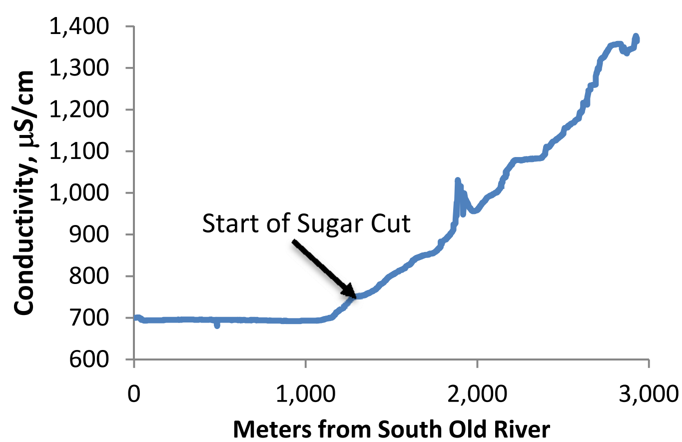

Figure 18. Surface-salinity transect conducted in Tom Paine Slough/Sugar Cut on April 16, 2009

Secondary Meander Channel

Stepped increases were sometimes observed in SOR upstream from Tracy Boulevard Bridge. This trend was apparent in all transects performed during May and June, 2009 (Figure 5). Conductivity during those transects increased by an average of 36% between meter 7,300 and Tracy Boulevard Bridge at meter 10,927 (range = 18% to 49%). Although a variety of factors may have created the stepped increases, several abridged transects in that vicinity revealed one set of contributing processes included a combination of diluting outflows from a secondary meander channel and tidal dispersion.

Multiple transect runs were conducted in SOR between meters 7,300 and 13,200 on March 29, 2010. The first run showed a large isolated conductivity slug positioned around meter 8,900 that probably originated from Tom Paine Slough or Paradise Cut (Figure 19). During the second run, the slug had shifted downstream with declining tide (Figures 19 and 20). Further, the excursion profile's leading edge exhibited a sharp drop around meter 9,060. Conductivity went from 1,357 to 1,086 µS/cm over a distance of 100 meters. A similar trend was observed on the third run at approximately the same location. The sharp drop occurred just downstream from the western convergence of a secondary meander channel at meter 9,060 (Figure 21). The upstream end of this meander connects with the main channel just north of the confluence with Tom Paine Slough. Water evidently flowed down the meander with outgoing tide, diluting conductivity in the main channel near meter 9,060. On run four, much of the slug had passed the convergence 2¼ hours after the start of the transects and had undergone extensive decay from lower salinity meander outflows.

Downstream of Tracy Boulevard Bridge, conductivity between all four transect runs fluctuated within a relatively narrow range (Figure 19). Slugs of high salinity water had apparently moved down SOR in succession during previous tidal cycles, undergoing dilution from lower salinity meander outflows and decay from tidal dispersion that integrated extremes. The outcome was a relatively homogenous mixture of waters downstream of Tracy Boulevard Bridge. Conductivity went from 966 µS/cm at the start of the transects to an average of 1,230 µS/cm at the end, a 27% increase. The processes describing trends shown in Figure 19 provide one explanation for the stepped increases observed in various transects presented in Figures 3 to 5.

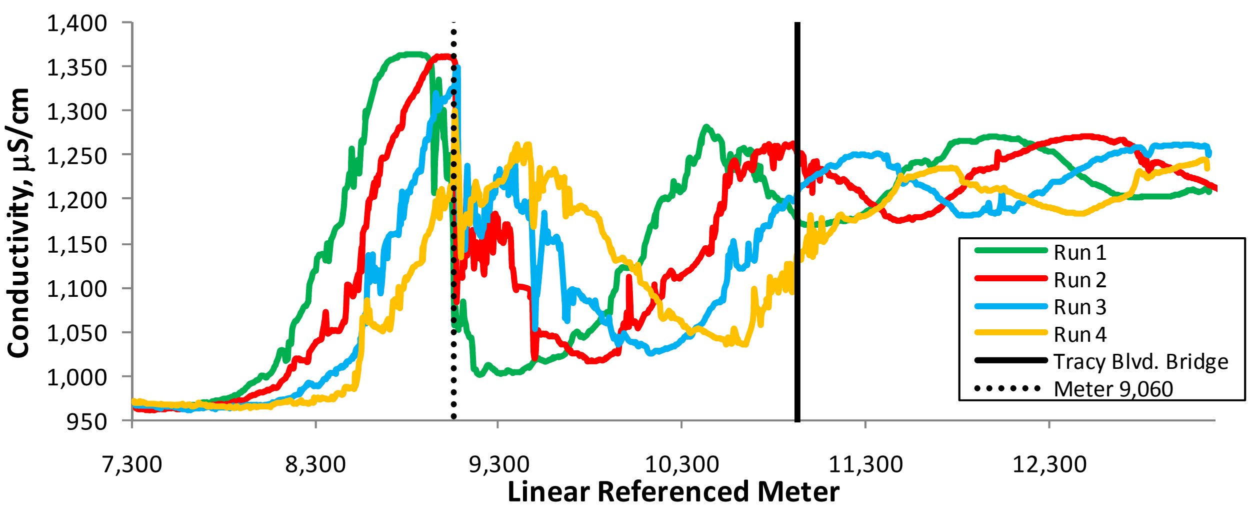

Figure 19. Multiple transect runs conducted in South Old River between meters 7,300 and 13,200 on March 29, 2010. Meter 9,060 is the location of a secondary meander channel convergence.

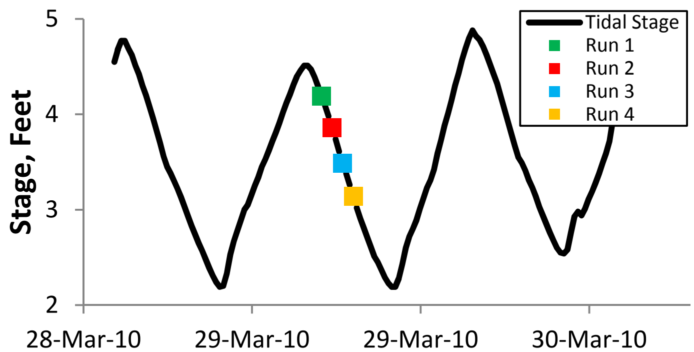

Figure 20. Tidal stage in South Old River at Tracy Boulevard Bridge (CDEC station OLD), March 28-30, 2010

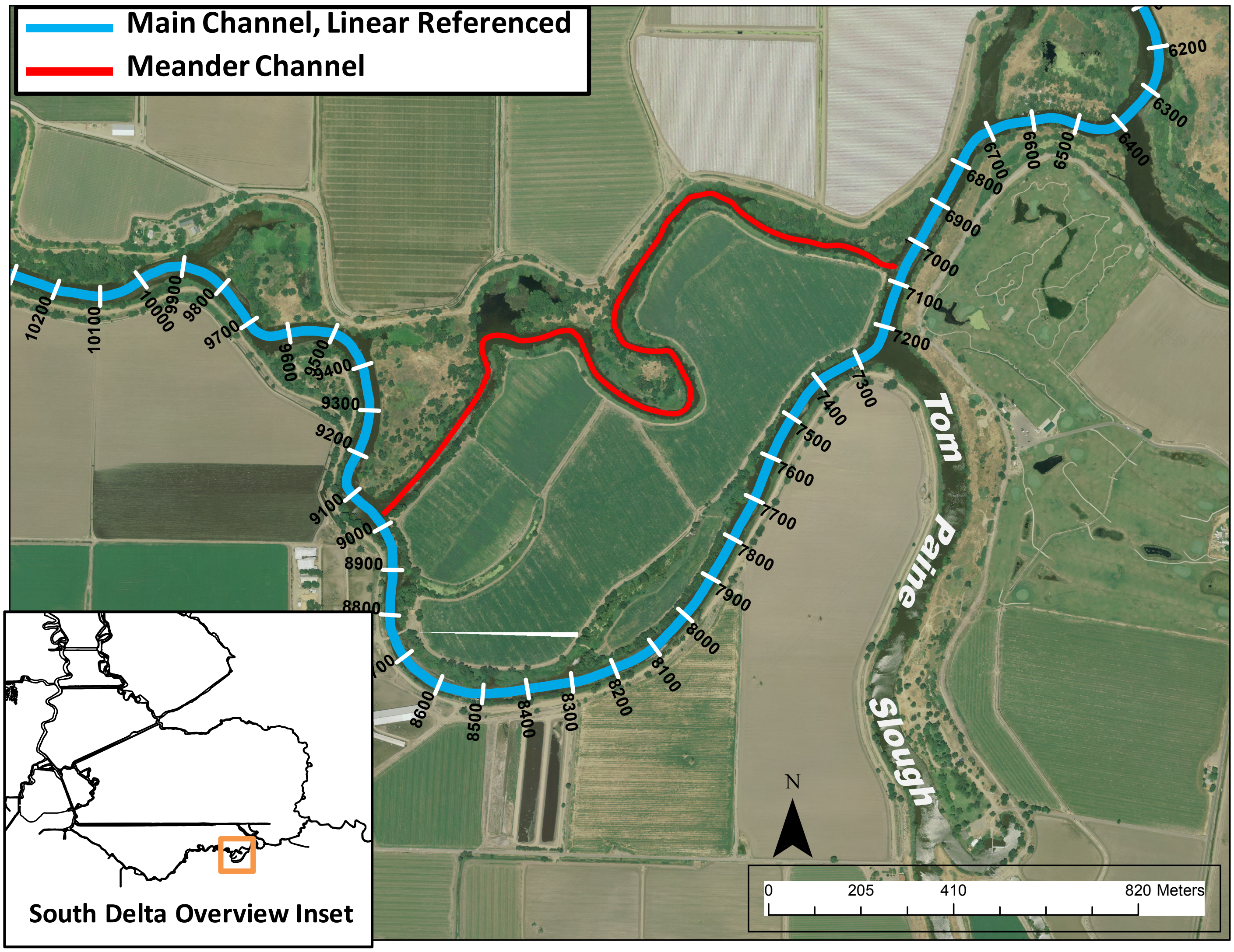

Figure 21. Secondary meander channel flowing around the South Old River main channel. Linear referenced values are in meters.

Meters 10,001 to 15,000

Tracy Boulevard Bridge Drain

The Tracy Boulevard Bridge compliance station is situated just downstream from a relatively large pumped conveyance. The Tracy Boulevard Bridge Drain receives drainage from agricultural lands south of SOR (SOR16, Table 1 and Figure 22). Its location at meter 10,450 is 477 meters upstream from the compliance station. The pumping facility is equipped with several units and three discharge pipelines plumbed over the levee. The discharge ends of the pipelines are submerged in SOR.

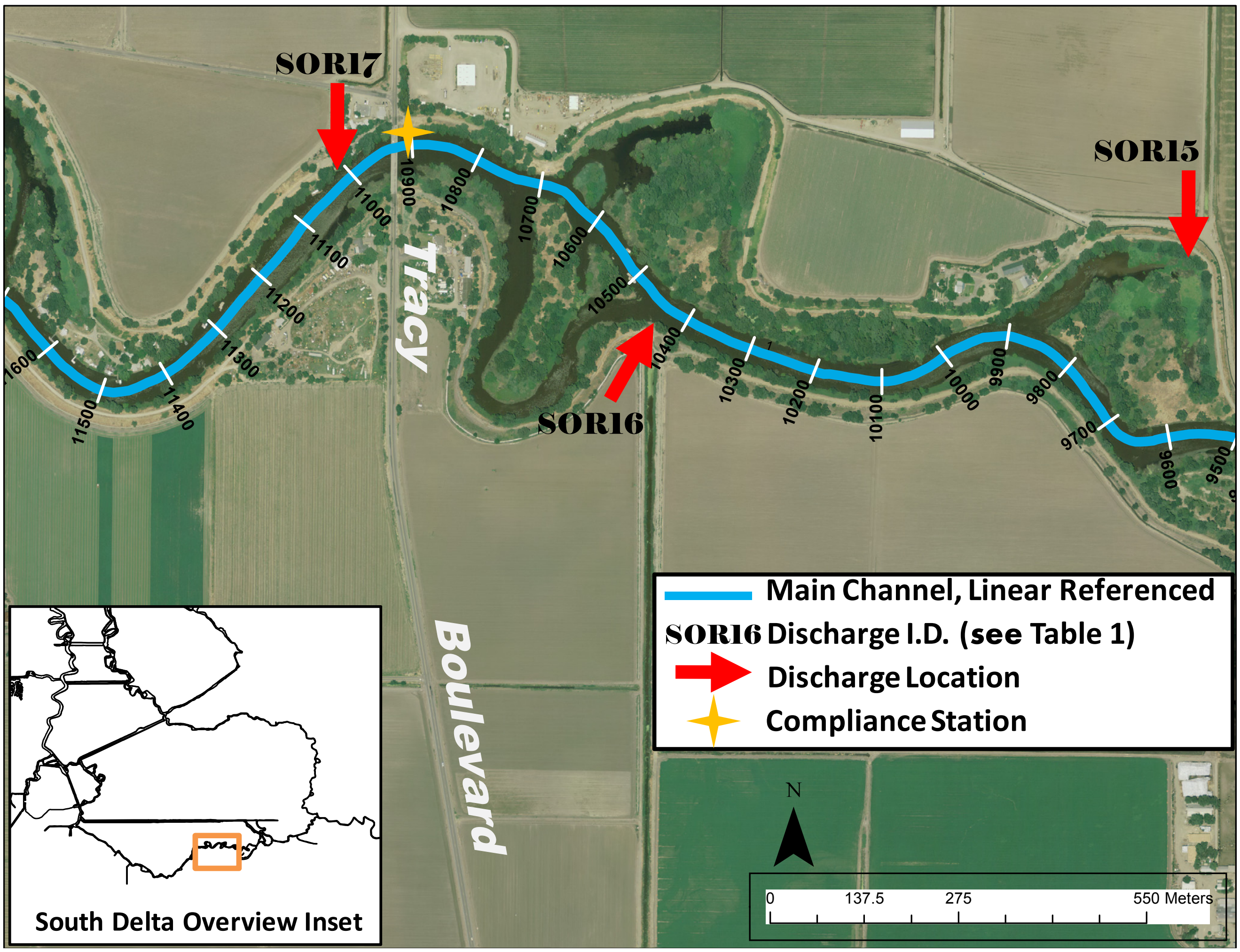

Figure 22. Location of Tracy Boulevard Bridge Drain (SOR16) in relation to the compliance station on South Old River. The linear referenced values are in meters.

Flow and water quality data for SOR16 are presented in Table 4 and Figure 23. Measurements were made at a corrugated pipe under-crossing of Tracy Boulevard located about 1,680 meters upstream from the pumping facility. Flow ranged from zero to 14.3 cfs and was highest

Table 4. Flow and water quality summary statistics for Tracy Boulevard Bridge Drain (SOR16) (Date range: January 2009 to December 2010)

Statistic	Flow (cfs)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Minimum	0.0	970	6.60	5.34
Maximum	14.3	6,196	28.6	127
Average	4.2	3,078	17.5	29.4
Median	3.0	2,280	17.4	19.3
Count (#)	28	88	85	79
Standard Deviation	4.2	1,652	4.9	27
Relative Percent SD (%)	101	54	28	91

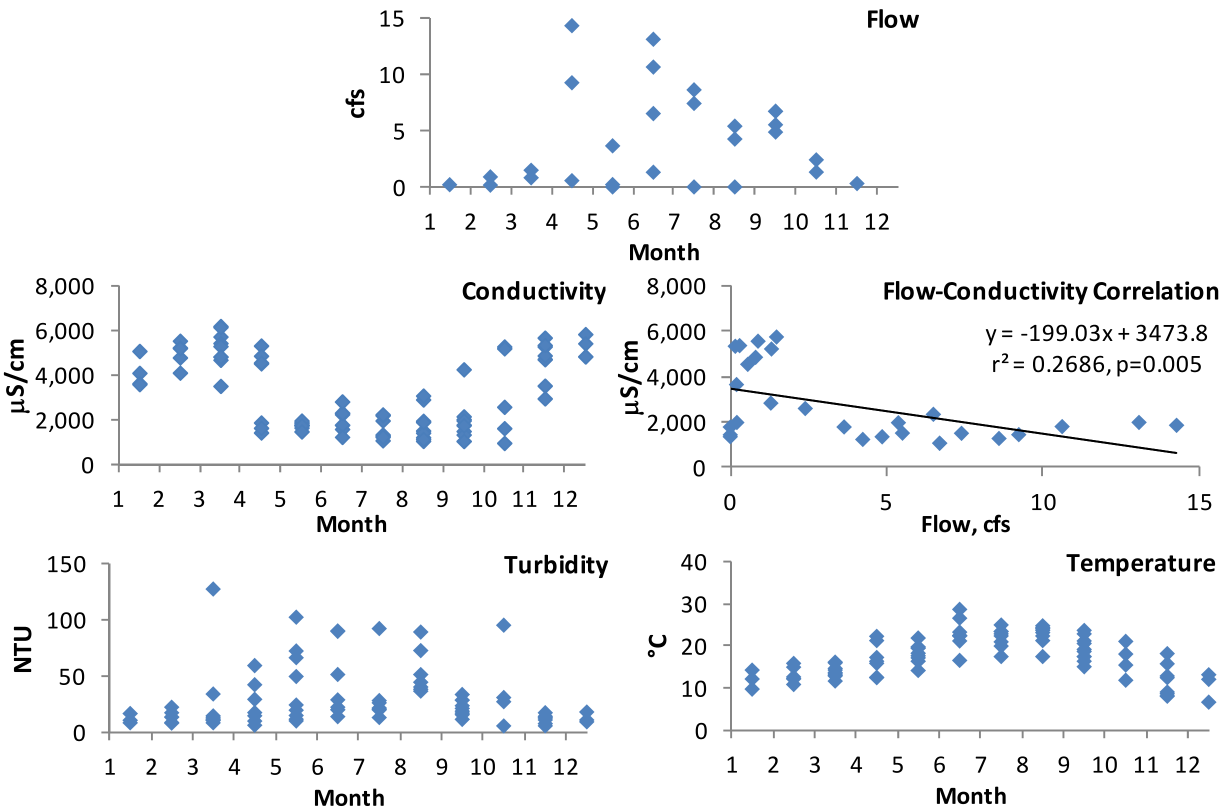

Figure 23. Seasonal flow and water quality trends for Tracy Boulevard Bridge Drain (SOR16)

during April through September although values were limited or non-existent for some months. Conductivity ranged between 970 and 6,196 µS/cm (median = 2,280 µS/cm) and was consistently lowest from May through October, implying a decrease due to irrigation activities during the growing season. Higher conductivities from November through March reflect several potentially contributing factors including an increase in saline groundwater composition, leaching of residual salts built up in the root zone during the growing season, or a reduction in diluting irrigation applications. Water temperature in SOR16 ranged from 6.6 to 28.6 °C and turbidity ranged from 5.34 to 127 NTU.

Effects of this pumped discharge on SOR salinity was evident in several transects including the run on September 15, 2009, when conductivity spiked above 1,100 µS/cm directly adjacent to SOR16 at meter 10,450 (Figure 7). Pumping was intermittent – assumed to be actuated by water level in the collector drain – so spikes adjacent to SOR16 were not always detected in the transects. Pump activity was visibly noticeable upon transect passage by the presence of foam and upwelling turbulence next to the submerged discharge pipelines.

Several abridged transects were conducted in SOR between meters 9,000 and 12,500 from April to July 2010 to more completely characterize SOR16's influence on salinity at the compliance station under changing tidal conditions. The transects are presented in Figure 24 in order of trend characteristics, not chronologically.

May 20, 2010 (Figure 24A): Conductivity during the first transect run remained unchanged past SOR16 as the discharge pumps were off. The pumps were on during the second run and a highly localized spike had formed. Conductivity increased from 360 µS/cm at meter 10,557 to over 600 µS/cm directly adjacent to SOR16. The third run revealed a similarly steep increase at SOR16 with levels tapering off as the plume of high salinity water migrated upstream. The upstream migration corresponded with a tidal stage (at Tracy Boulevard Bridge) that increased from 3.4 to 4.0 feet between the first and third runs (see secondary vertical axis in Figure 24A). Erratic conductivity oscillations during runs two and three indicate continued mixing of pumpage with lower salinity in-channel water. The SOR16 discharge pumps were off during runs four through seven and the slug stagnated and decayed as tide continued to rise.

Discharges prior to the two hour transect period did not produce any surviving slugs as indicated by the relatively uniform levels downstream of SOR16. Pumping was apparently infrequent enough to allow dispersion processes to diminish any localized discharge accumulation. Instead, pumpage became assimilated in-channel at both the upstream and downstream ends over time. In this manner, a gradually increasing trend was sustained throughout a relatively long stretch of river as revealed on run one. Transect conductivity increased from 300 µS/cm at meter 9,000 to an average of 400 µS/cm at Tracy Boulevard Bridge, a 33% increase over 1,927 meters.

May 5, 2010 (Figure 24B): Conductivity during the first transect run increased from 300 µS/cm at meter 9,000 to a peak of 514 µS/cm just downstream from Tracy Boulevard Bridge – a similar trend was observed on runs two through four. The discharge pumps were off upon passage of SOR16 during all runs. Although tidal stage increased by 0.7 feet, water movement was limited. The broad slug of high salinity water had essentially stagnated with a crest centered in close proximity to the compliance station during the two hour transect period. While the slug may have been created from SOR16 discharges preceding the transects, confirmation cannot be determined from this set of transects alone.

April 22, 2010 (Figure 24C): The SOR16 pumps were active for the three hours encompassing all transect runs as reflected in the sometimes erratic fluctuations downstream of meter 10,450.

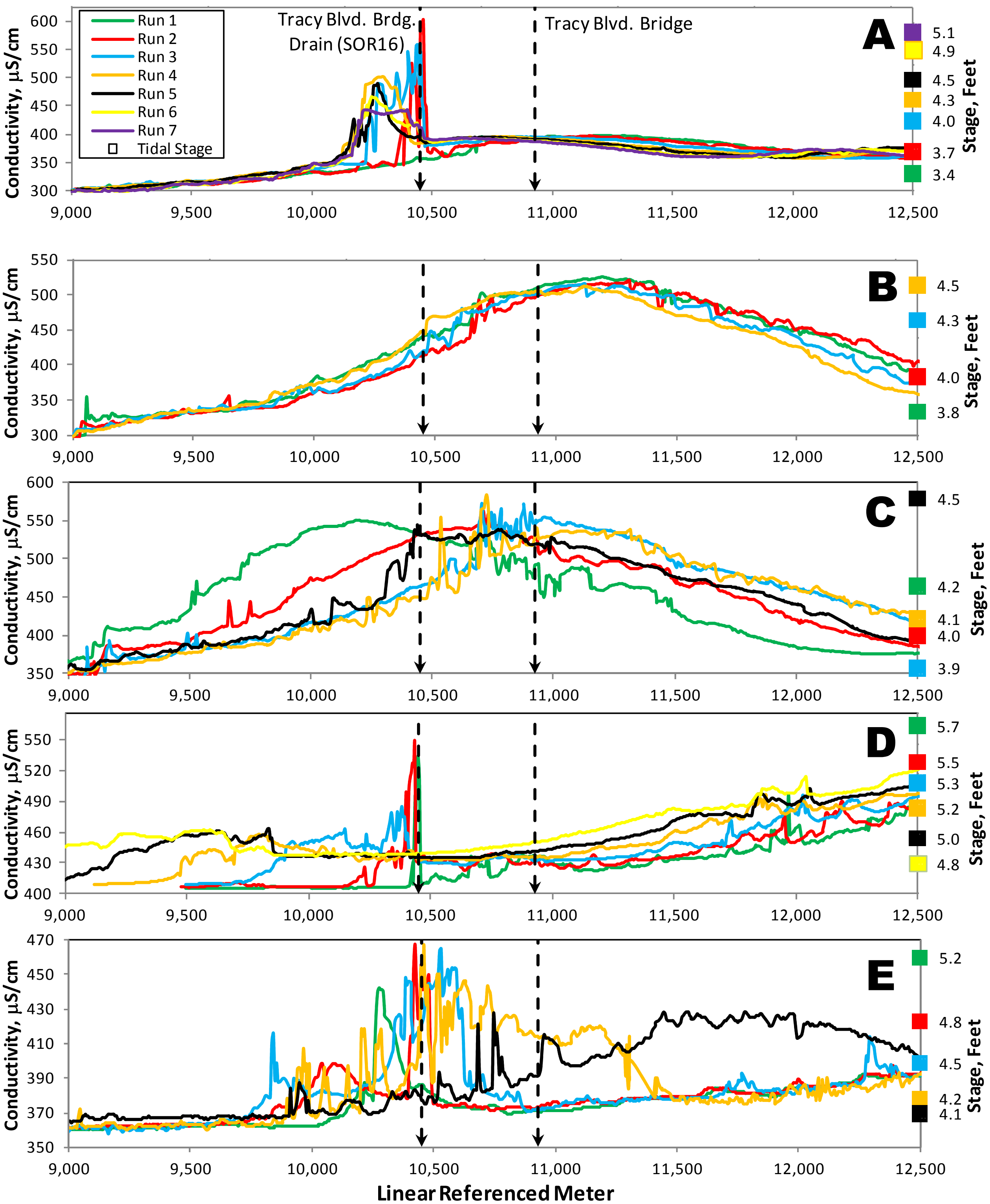

Figure 24A-E. Multiple transect runs conducted in South Old River between meters 9,000 and 12,500 on May 20, 2010 (A), May 5, 2010 (B), April 22, 2010 (C), June 24, 2010 (D), and July 7, 2010 (E). Tidal stage from the Tracy Boulevard Bridge station is shown on the secondary vertical axis.

On runs one to three, a broad slug moved downstream corresponding with a tidal stage that declined from 4.2 to 3.9 feet. It stagnated between runs three and four with a crest approximately centered on Tracy Boulevard Bridge. Tide reversed prior to run four and upstream movement was detected on run five as discharges continued. Similar to the May 5, 2010, transects in Figure 24B, the crest of a large conductivity slug fluctuated around the compliance station during the transect period, inflating levels there compared with those upstream and downstream. Further, the same segment of water moved back and forth past SOR16 with bidirectional tidal flows, constantly receiving pumpage that added to the salinity of the slug.

June 24, 2010 (Figure 24D): A highly localized spike at meter 10,450 was detected on transect runs one and two when the SOR16 pumps were on. Subsequent runs occurred after pumping had stopped. During runs three to six, the initial spike had broadened and moved upstream as tidal stage declined from 5.3 to 4.8 feet. More than 2½ hours passed between runs one and six. Upstream movement with declining tide revealed residual directional flow from the preceding high tide. Discharges prior to the transect period were evident surrounding meter 12,000 as indicated by the relatively uneven levels. These trends indicate that pumping was not frequent or voluminous enough to form isolated slugs. Instead, conductivity gradually increased over time from intermittent discharges and bidirectional tidal flow dispersion.

July 7, 2010 (Figure 24E): The first transect run showed a young conductivity slug positioned just upstream of SOR16 when the pumps were off. Tide had been declining for four hours prior to the start of the run. Continued upstream flow on a falling tide was observed on the second run along with a localized spike at SOR16 due to recent pump activity. Flow reversed before the third run and an enlarged slug began moving downstream. Run three also revealed a sharp spike around meter 9,840 which likely originated from a nearby agricultural drain that discharges to a dead-end meander channel just upstream from that location (SOR15, Figure 22). By run four, the slug had expanded and moved farther downstream, exhibiting wide oscillations immediately below SOR16 due to continued pumping. Oscillations were also evident upstream of SOR16 indicating that discharges from SOR15 had persisted after run three, producing pockets of elevated conductivity that were moving downstream incompletely mixed. On the fifth run, more than eight hours after run one, the large slug had undergone extensive decay, declining and broadening over a wide stretch of river farther downstream. Pump activity continued to produce erratic fluctuations below SOR16. These transects confirm that SOR16 is capable of generating broad slugs of saline water like those observed in Figures 24B and 24C.

Lammers Road Drain

Located at meter 14,724, Lammers Road Drain (SOR20, Table 1 and Figure 2) is a pumped discharge that is considered a routine source of elevated salts to SOR due to its frequently observed pumping activity and relatively saline nature. Conductivity in SOR20 from four measurements made during this study averaged 1,871 µS/cm (range = 1,505 to 2,421 µS/cm).

Several transects show this drain measurably influenced salinity in SOR. Transects on May 14 and June 11, 2009, revealed modest spikes downstream from the location of SOR20 (Figure 5). This source discharges to a short secondary meander that connects with the main channel upstream and downstream from the linear referenced location assigned to SOR20. Sources not positioned on the main SOR channel were assigned location values perpendicular to the linear referenced path. The meander joins with the main channel around meters 14,900 (western convergence) and 14,700 (eastern convergence). Influence from meander outflows to the main channel can extend beyond such boundaries during tidal movement due to the gradual lateral mixing that can occur at the confluence of two parallel waterways.

Meters 15,001 to 24,000

Bethany Road Drain

Like Lammers Road Drain, Bethany Road Drain discharges to a secondary meander south of the main channel. The pumping facility consists of three units. The discharge location was assigned a linear referenced meter of 17,747 (SOR24, Table 1 and Figure 2). Discharges from SOR24 can be seen in Figure 25 as a white surface plume several hundred meters from either the eastern or

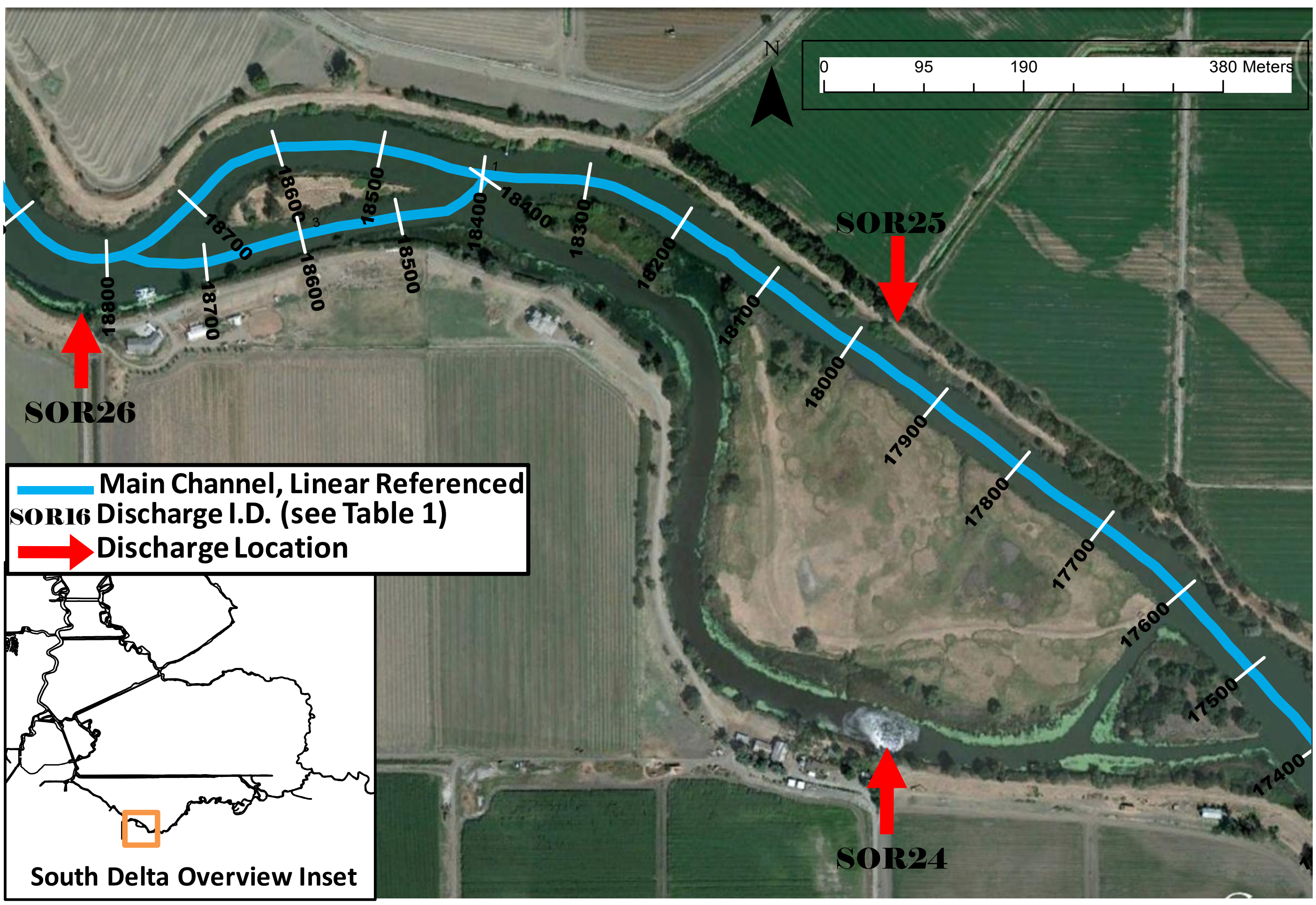

Figure 25. Location of Bethany Road Drain (SOR24) on a secondary meander channel of South Old River. Linear referenced values are in meters. Two linear referenced transects were included around a small island to account for boat routes that sometimes varied between dates.

western convergences. Meander outflows can enter the main channel at the first western convergence centered on meter 18,400 followed by the second at meter 18,700. Influence from meander outflows can extend beyond such boundaries during tidal movement due to the gradual lateral mixing that can occur at the confluence of two parallel waterways. At the first western convergence, the linear referenced pathway splits into two courses around a small island. Both pathways were needed to account for boat routes that sometimes varied between transects. Source waters to SOR24 include agricultural drainage and possibly urban runoff from the City of Tracy and groundwater.

Flow and water quality measurements in the collector drain upstream from the SOR24 pumping facility are presented in Table 5 and Figure 26. The limited number of flow measurements ranged from zero to 16.5 cfs and were generally highest between June and September. Conductivity ranged between 596 and 5,294 µS/cm with a median of 1,824 µS/cm. Conductivity was consistently lowest during the growing season and exhibited a modest inverse correlation with flow. The data imply that salinity declined as a result of agricultural irrigation activities. Temperature ranged from 4.5 to 24.1 °C and turbidity ranged from 4.0 to 75 NTU.

Table 5. Flow and water quality summary statistics for Bethany Road Drain (SOR24) (Date range: January 2009 to December 2010)

Statistic	Flow (cfs)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Minimum	0.0	596	4.5	3.99
Maximum	16.5	5,294	24.1	75
Average	7.2	2,503	16.9	31.4
Median	7.1	1,824	17.4	30.5
Count (#)	27	82	81	75
Standard Deviation	5.4	1,439	4.89	16.5
Relative Percent SD (%)	75	58	29	53

Effects of SOR24 can be seen in transects on July 23 and August 12, 2009; conductivity rapidly increased above the drain's location (Figure 6). The increase upstream from the drain can be explained by higher tidal conditions during the transects that would have forced upstream, any slug formed from meander outflows at the western convergence. Drainage-dominated water in the meander may have also been tidally forced into the main channel via the eastern convergences between meters 17,400 and 17,600.

Most of the transects shown in Figures 3 to 7 exhibited gradually rising trends before peaking in the western end of SOR, often culminating in large, broad zones of elevated conductivity. The saline nature, relatively large size, and location within western SOR of Bethany Road Drain establishes this source as a major contributor to these observed trends. Several abridged transects conducted in the vicinity provided supporting evidence.

Figure 27 shows five transect runs encompassing meters 17,500 to 21,300 on July 7, 2010. All runs navigated the northern linear referenced route around the small island shown in Figure 25.

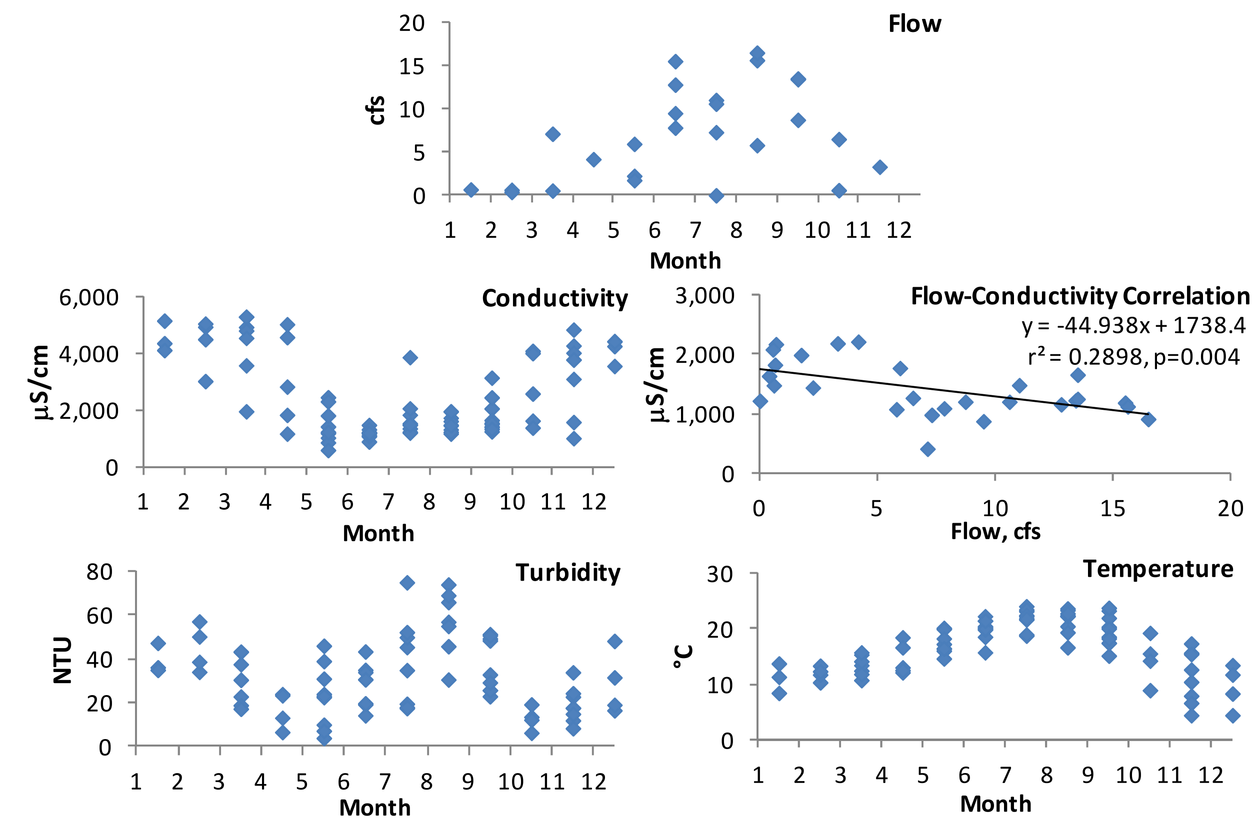

Figure 26. Seasonal flow and water quality trends for Bethany Road Drain (SOR24)

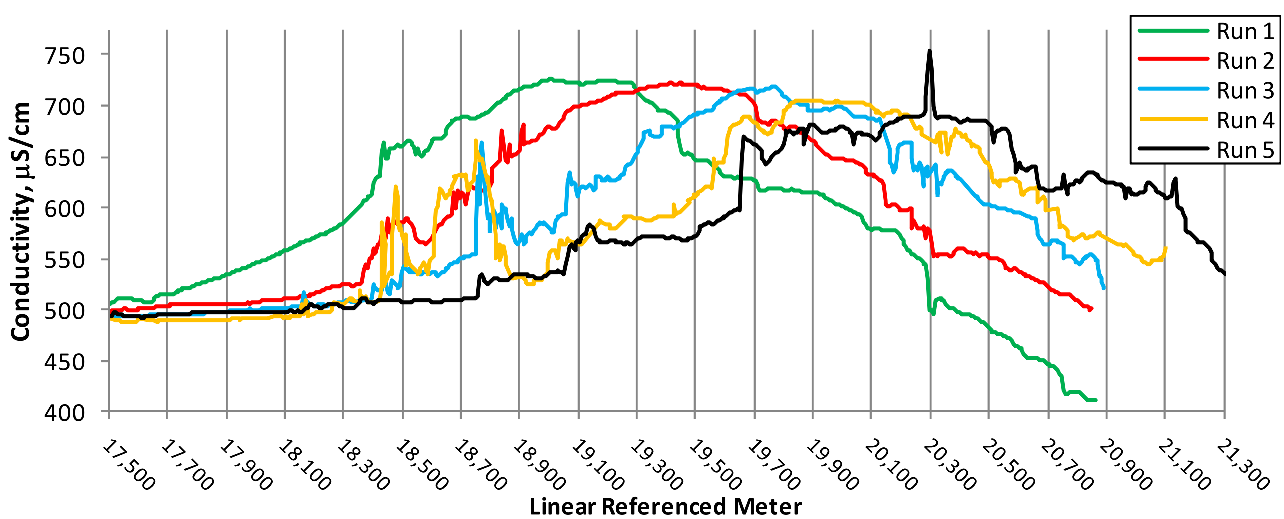

Figure 27. Multiple transect runs conducted in South Old River between meters 17,500 and 21,300 on July 7, 2010

Run one revealed a broad conductivity slug centered on meter 19,100 with a small uptick on the upstream limb at meter 18,500. This location corresponds with the farthest extent of SOR24's first western meander convergence with SOR. Meander water was apparently drawn into the main channel – along with discharges from SOR24 – causing the uptick in conductivity. Tide during the first run was over four hours past a higher-high (Figure 28). Downstream flow was detected on the second run as tide continued to decline. Also detected was a similar uptick at the same location as the first run. A sharp spike was observed on the third run between meters 18,700 and 18,900, a stretch of river downstream from the second western meander convergence. Inflated conductivity in SOR from meander outflows expanded to between meters 18,400 and 18,900 on the fourth run indicating that tide had dropped to a level that resulted in greater outflow volumes and/or a reduction of in-channel dilution capacity. The fifth run was conducted on a tidal trough and meander outflows were not obvious eight hours after the start of the transects.

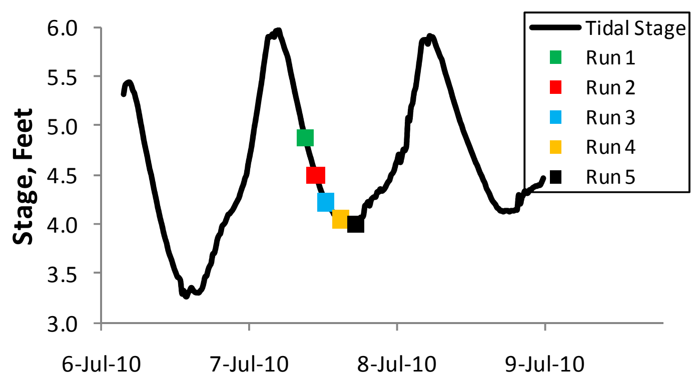

Figure 28. Tidal stage in South Old River above the temporary barrier site (CDEC station OAD), July 6-9, 2010

The abridged transects show that SOR24 contributed to a large, broad slug of high conductivity in western SOR created prior to the transect period. The slug remained intact on a tidal trough and would have been forced upstream upon flow reversal. The data provide evidence that SOR24 is a primary source perpetuating zones of elevated conductivity in the western end of SOR as shown in Figures 3 to 7. The zones can be created when discharges accumulate in the 1,100 meter-long meander and then become drawn into the main channel with downstream flow. Over several tidal cycles, the same segment of water moves back and forth past the convergence multiple times, repeatedly becoming dosed with meander outflows. In this manner, the zone of high salinity may be maintained or grow in size depending on numerous potentially influencing factors such as the magnitude of salt loading, in-channel flow, tide, etc.

Wicklund Cut Drain

Another source of saline water to the western end of SOR is Wicklund Cut Drain (WC1, Table 2 and Figure 2). Passive flows from this drain enter the upper reach of Wicklund Cut, a dead-end artificial channel that intersects SOR at meter 19,050 (SOR28, Table 1 and Figure 2). Drainage must traverse 1,268 meters of this waterway prior to reaching SOR. Therefore, similar to discharges to Sugar Cut from SC1, outflows from WC1 are diluted upon comingling with water in Wicklund Cut before reaching SOR. Source waters to WC1 include agricultural drainage, urban runoff from the City of Tracy, and possibly groundwater.

Flow in WC1 was continual throughout the study period (range = 2.40 to 26.1 cfs) and was generally highest during the months of May through September (Table 6 and Figure 29). Conductivity ranged between 919 and 2,675 µS/cm and was inversely correlated with flow. Temperatures ranged from 9.4 to 23.0 °C and turbidity ranged from 11.5 to 177 NTU.

Table 6. Flow and water quality summary statistics for Wicklund Cut Drain (WC1) (Date range: January 2009 to December 2010)

Statistic	Flow (cfs)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Minimum	2.40	919	9.4	11.5
Maximum	26.1	2,675	23.0	177
Average	13.7	2,172	17.2	57.0
Median	14.4	2,142	17.5	46.8
Count (#)	28	86	85	79
Standard Deviation	6.7	354	3.28	36.7
Relative Percent SD (%)	48	16	19	64

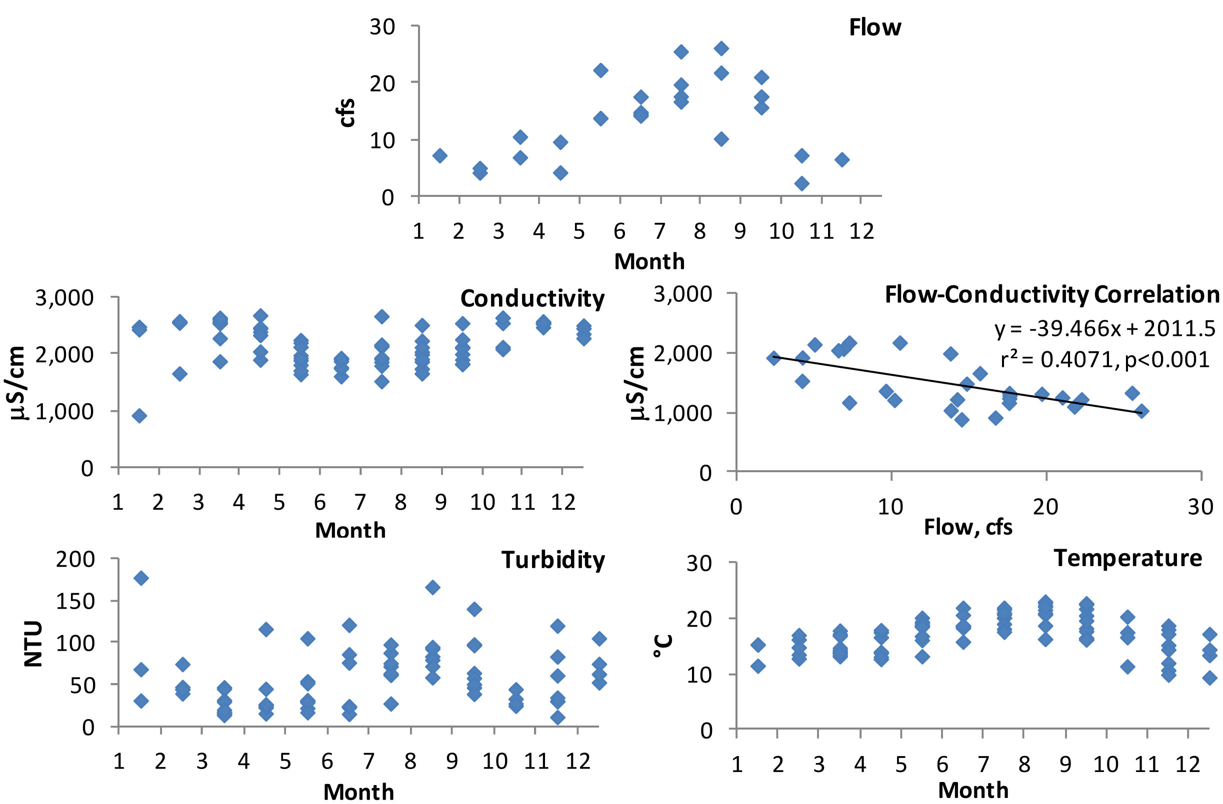

Figure 29. Seasonal flow and water quality trends for Wicklund Cut Drain (WC1)

Effects of Wicklund Cut outflows on SOR salinity were nearly absent from transects shown in Figures 3 through 7. One possible exception included a small uptick in conductivity detected near the waterway mouth on September 15, 2009 (Figure 7). Also, slight increases were present in the vicinity of Wicklund Cut during transect runs three to five conducted on July 7, 2010 (Figure 27), although this may just reflect residual plumes from SOR24 discharges flowing downstream incompletely mixed.

Besides the dilution that drainage from WC1 undergoes within Wicklund Cut, this drain's potential to influence transect conductivity may have been further diminished by pumped diversions. A large pumping facility (perhaps the largest along SOR) is situated at the southern end of Wicklund Cut. The primary owner, West Side Irrigation District, is licensed by the State Water Board to divert 82.5 cfs of water from SOR (SWRCB eWRIMS GIS data query, 2012). Diversions may have intercepted all or a portion of WC1 outflows during periods of pumping. This was supported by field observations noting that drainage was almost always moving towards the pumping plant after entering Wicklund Cut. Therefore, discharges from WC1 may, at times, have little or no direct influence on salinity in SOR at the mouth of Wicklund Cut.

Mountain House Creek

Mountain House Creek is a natural perennial stream that intersects SOR at meter 20,268 (SOR31, Table 1 and Figure 2). The 44 km^2 watershed (17 mi^2, SWRB 1958) drains the residential community of Mountain House as well as broad swaths of open land. A limited number of flow measurements ranged from 0.48 to 2.5 cfs (Table 7) – all but one was below 1 cfs so monitoring was discontinued. Conductivity consistently fluctuated near 2,000 µS/cm and usually declined during storm events (Table 7 and Figure 30). Temperature ranged from 9.3 to 21.3 °C and turbidity ranged between 2.16 and 31 NTU. Water in Mountain House Creek predominantly originated as groundwater effluence based on continuous flows, relatively high background salinities, and persistently low turbidities.

Although this source contributes to SOR's overall salt load, evidence of direct influence was not definitively apparent in any of the full river transects. The low flows were likely diluted before reaching SOR; the creek widens into a tidal waterway upstream from the confluence where water from SOR can commingle with creek flows. Several of the abridged transects in Figure 27 did indicate conductivity changes at the tributary with outgoing tide. Run one showed a temporary

Table 7. Flow and water quality summary statistics for Mountain House Creek (SOR31) (Date range: January 2009 to December 2010)

Statistic	Flow (cfs)	Conductivity (µS/cm)	Temperature (°C)	Turbidity (NTU)
Minimum	0.48	594	9.3	2.16
Maximum	2.5	2,023	21.3	31
Average	1.0	1,783	17.2	6.4
Median	0.8	1,895	17.2	4.6
Count (#)	8	65	65	59
Standard Deviation	0.6	307	2.63	5.1
Relative Percent SD (%)	66	17	15	80

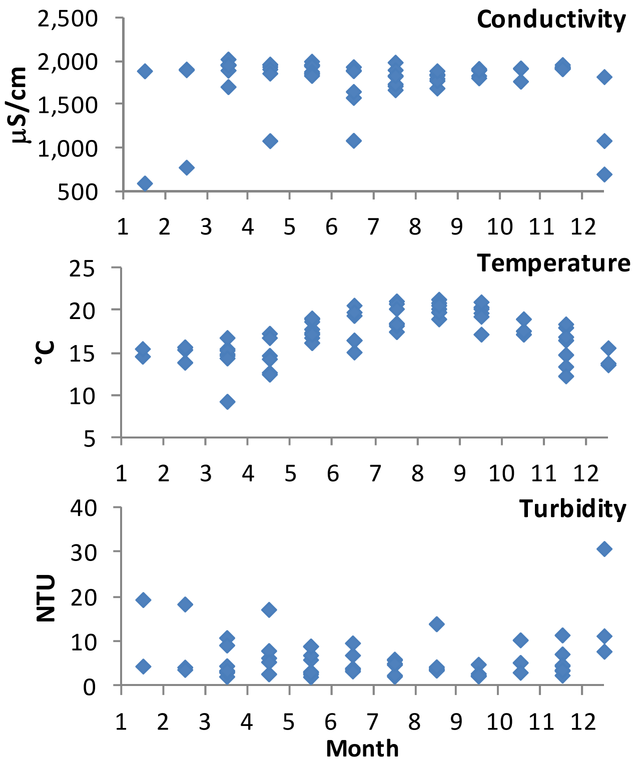

Figure 30. Seasonal water quality trends for Mountain House Creek (SOR31)

drop in conductivity just downstream from the mouth at meter 20,268. This may be an indication of lower salinity water from SOR, forced up the waterway during the preceding incoming tide, flowing out with little or no mixing with creek water on the outgoing tide. Run five showed a sharp spike at the same location due to the apparent predominance of creek flows leaving the waterway after much of the tidal water had drained out.

River Salinity Increases

Multiple River Transects

One set of multiple transects was conducted on July 7, 2010, over a large section of SOR encompassing several major discharge and tributary inputs (Figure 31). The upstream boundary for runs one, four, and five was the bifurcation with Doughty Cut at meter 5,550. The upstream boundary for runs two and three was around meter 8,770. Certain data and trends from these transects have been previously discussed in greater detail. All runs reveal a progression of increasing salinity throughout SOR from several major intermittent inputs.

A slight uptick in conductivity at Paradise Cut (meter 6,400) was detected on the first run as tide was 4½ hours past a higher-high (Figure 31). Water entering SOR from Paradise Cut was moving upstream as indicated by the lower conductivity immediately below the confluence.

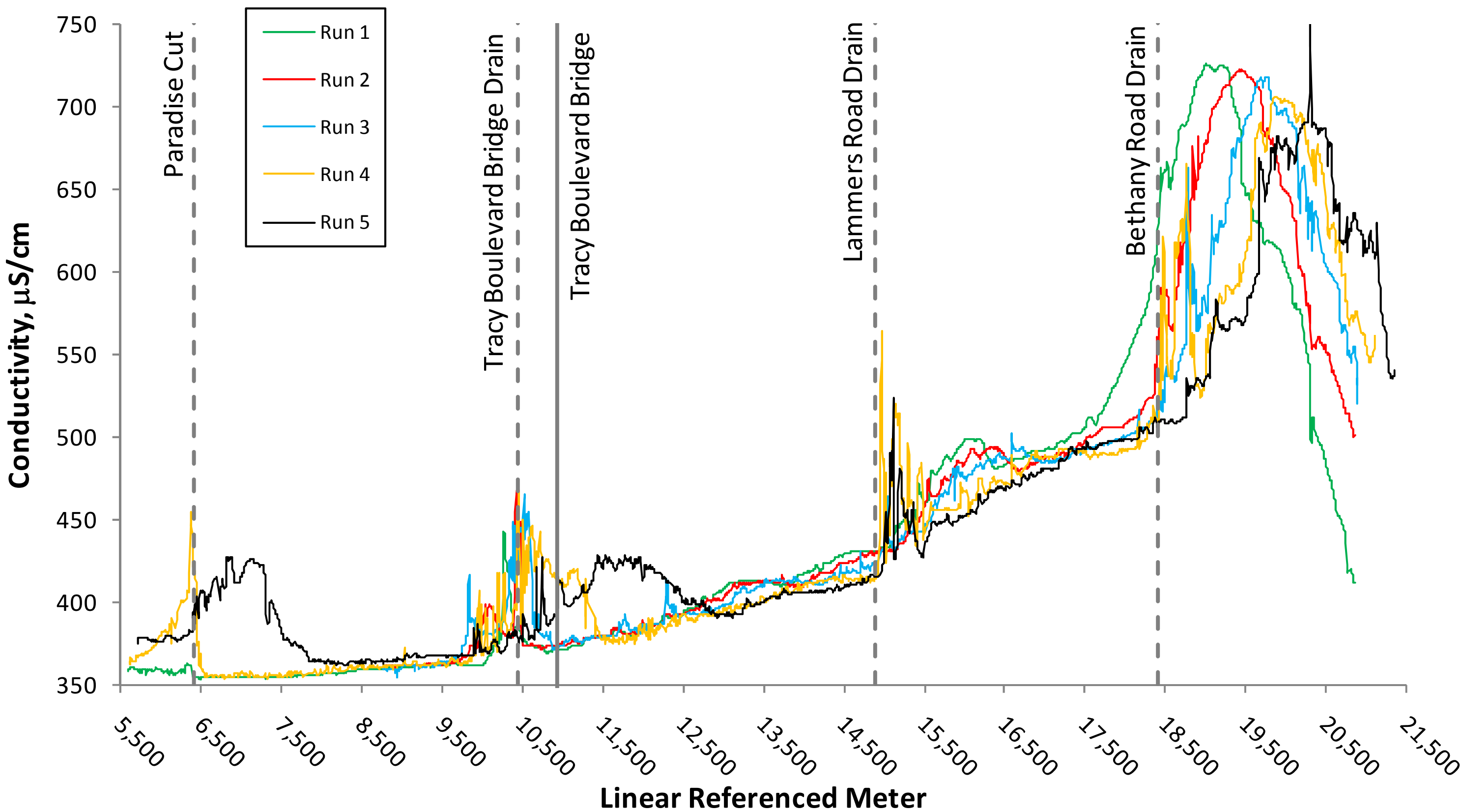

Figure 31. Multiple transect runs conducted in South Old River between meters 5,500 and 21,500 on July 7, 2010

The fourth run showed higher salinity outflows continuing upstream on a declining tide 5½ hours later. Flow reversed prior to run five and the newly-formed slug repositioned below the confluence coincident with a tidal trough. Approximately eight hours had elapsed between the first and fifth runs. This sequence of outflow events duplicated those previously discussed whereby saline water from Paradise Cut was drawn into SOR on a declining tide, flowed upstream, then reversed direction and began moving downstream as an isolated slug. The downstream-migrating slugs were shown to remain intact with minimal dispersion, eventually resulting in wide swings in conductivity at the Tracy Boulevard Bridge compliance station. They also became heavily diluted by meander outflows and tidal dispersion that, along with the amalgamation of successive releases from Paradise Cut over several tidal cycles, yielded stepped increases.

Transects in Figure 31 also show saline contributions from Tracy Boulevard Bridge Drain at meter 10,450 that were detailed earlier in Figure 24. This pumped discharge was shown to generate broad slugs of conductivity positioned near the compliance station. Discharges also gave rise to localized spikes and gradually rising levels. All of these trends were apparent in Figure 31.

Influence from Lammers Road Drain can be seen in Figure 31 starting at meter 14,900. This pumped drain discharges to a short meander that merges with the main channel at that location.

Wide conductivity oscillations detected immediately downstream during runs four and five indicate the comingling of saline pumpage and channel water. Runs one to three reveal a diminishing slug between meters 15,500 and 16,500 that apparently formed from discharges prior to the transects. During the transect period, this slug was assimilated into the surrounding water so that by run five, conductivity gradually trended upward with no evidence of its existence. The repetitive action of periodic discharges and tidal dispersion over time contributed to a gradually increasing trend downstream from Lammers Road Drain.

Bethany Road Drain is located on a long secondary meander that merges with the main channel centered around meter 18,400. Pumped discharges accumulate in the meander and then become drawn into the main channel at the downstream convergence with outgoing tidal flow. The effects of these meander outflows on SOR salinity, as shown in Figure 31, have been assessed earlier in detail. The assessment concluded that this discharge is a primary source contributing to the creation, maintenance, or growth of large, broad zones of high conductivity in western SOR. The zones are perpetuated over time by a combination of recurring discharges and bidirectional tidal flows that repeatedly move them past the meander convergence. The zones can be dosed multiple times from meander outflows upon passage of the downstream convergence with each declining tidal cycle.

Salinity Increases

South Old River transect salinity increases are presented in Figure 32. Maximums were averaged from peak conductivities in western SOR prior to the decline from water shifting upstream with tidal flow. As such, isolated slugs farther upstream sometimes exhibited higher levels but were excluded from the analysis.

Conductivity maximums ranged from 639 to 1,391 µS/cm and were 5% to 125% above initial measurements at the eastern transect boundary (Table 8 and Figure 33). Initial transect conductivities of 305 to 1,086 µS/cm were highest during the first few months of each year. Levels were relatively high (826 to 1,086 µS/cm) during February 10 through April 1, 2009, a below normal water year type in the San Joaquin Valley following a critical one the previous year. Initial levels from transects conducted between January and March 2010 were lower ranging from 786 to 981 µS/cm, reflecting a greater abundance of available water supplies from an above normal water year in the San Joaquin Valley.

Maximum conductivities were 52 to 444 µS/cm above initial levels (Table 8 and Figure 33). Relative increases were 10% or less for three transect runs and greatest during two runs in 2009 – April 28 (121%) and May 14 (125%). An explanation for those elevated percentages was related, in part, to lower salinity water entering SOR from the San Joaquin River. An upsurge in reservoir releases during the Vernalis Adaptive Management Plan (VAMP) spring pulse flow period, generally extending from mid-April to mid-May in any given year, created the low salinity conditions. During 2009, daily flow averaged 2,040 cfs on April 28 with a corresponding conductivity of 314 µS/cm (source: CDEC query from stations VNS and SJR). Conductivity averaged 253 µS/cm on May 14 followed by a peak spring flow of 2,555 cfs on May 17. Consequently, the high relative increases in transect conductivity on those dates were not necessarily due to unusually elevated salt augmentation as the percentages would imply.

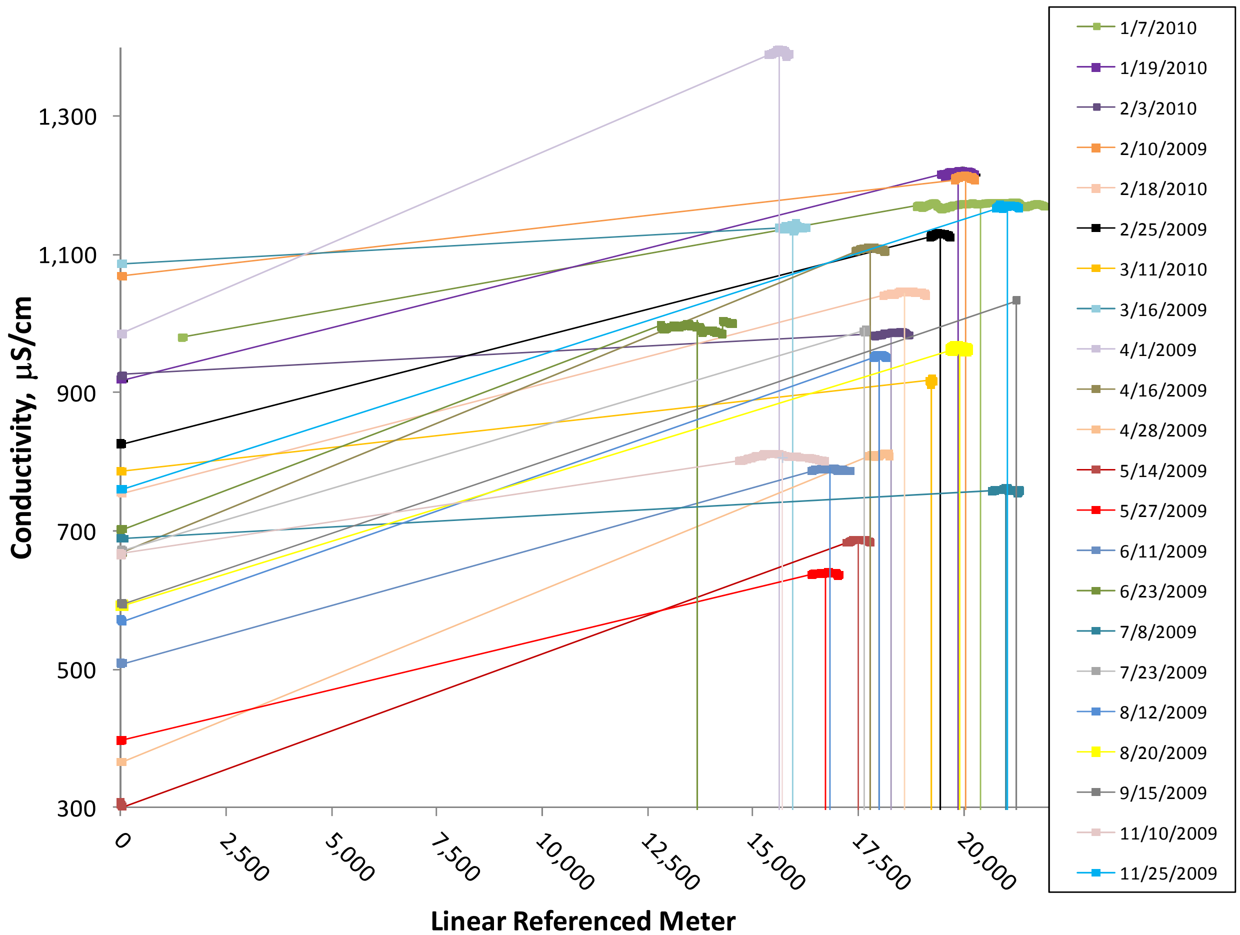

Figure 32. South Old River transect salinity increases. Maximum conductivities were averaged from values within 0.5% of the highest measurement reached in western South Old River prior to declining from lower salinity water shifting upstream with tidal flow. Initial conductivities were averaged from values measured within the first 50 meters of each transect.

Maximum conductivities were positioned between meters 13,673 and 21,243 – all upstream from the temporary barrier installation site at meter 22,415 (Table 8 and Figure 32). The median and average positions of 18,140 and 18,290 meters, respectively, were near Bethany Road Drain's first downstream meander convergence centered on meter 18,400. The close proximity of the drain outlet to the centralized positions of maximum conductivity is further substantiation of an earlier conclusion that this discharge was a primary source for creating, maintaining, or expanding large zones of elevated salinity in western SOR.

Maximum conductivity positions were inversely correlated with tidal stage when excluding data within the barrier installation period (Figure 34). The correlation makes sense from the standpoint that a particular segment of water, as represented by conductivity maximums, would shift back and forth in the channel with tidal movement. A higher tidal stage signifies a travel distance farther upstream. The relationship describes a constant re-positioning with tide of maximum salinity zones in western SOR.

Table 8. Initial and maximum conductivities for South Old River transects

Date	Initial Cond. (µS/cm) 1/	Maximum Cond. (µS/cm) 2/	Increase (µS/cm) 3/	Increase (%)	Maximum Position (meter)
2/10/2009	1,069	1,211	142	13	20,026
2/25/2009	826	1,128	302	37	19,443
3/16/2009	1,086	1,139	52	5	15,942
4/1/2009	985	1,391	407	41	15,612
4/16/2009	669	1,108	439	66	17,787
4/28/2009	366	810	444	121	17,990
5/14/2009	305	686	381	125	17,493
5/27/2009	397	639	241	61	16,719
6/11/2009 4/	509	789	280	55	16,836
6/23/2009	702	994	291	41	13,673
7/8/2009	689	759	70	10	20,997
7/23/2009	672	988	316	47	17,649
8/12/2009	571	953	382	67	18,002
8/20/2009	592	964	372	63	19,887
9/15/2009	595	1,034	438	74	21,243
11/10/2009	665	807	142	21	15,682
11/25/2009	760	1,169	409	54	21,046
1/7/2010	981	1,173	192	20	20,382
1/19/2010	919	1,218	299	33	19,847
2/3/2010	925	986	61	7	18,279
2/18/2010	755	1,044	289	38	18,601
3/11/2010	786	916	130	17	19,232

1/ Data averaged from first 50 meters of transect

2/ Data averaged within 0.5% of maximum value

3/ Maximum conductivities were statistically higher than initial conductivities for all dates ($p<0.001$, Mann-Whitney U test) except 9/15/2009 due to a small number of maximum values

4/ Initial and maximum conductivities 8% to 10% underestimates

Geochemical Analysis

Water quality samples for major minerals were collected from SOR at the head of Middle River (meter zero) and Tracy Boulevard Bridge (Tracy) during the study period. Mineral levels were consistently higher at Tracy than at meter zero (Table 9). Salinity (TDS and conductivity) averaged 17% to 20% greater at Tracy. Average increases between stations were lowest for total alkalinity (11%) and highest for chloride (26%).

Both SOR stations exhibited anionic-cationic compositions dominated by sodium and chloride, a general definition of their water types. Sodium composed from 47% to 57% of the cationic content at meter zero, followed by calcium (23%-29%) and magnesium (21%-25%). These percentages were nearly identical for the cationic content at Tracy. Composition differences

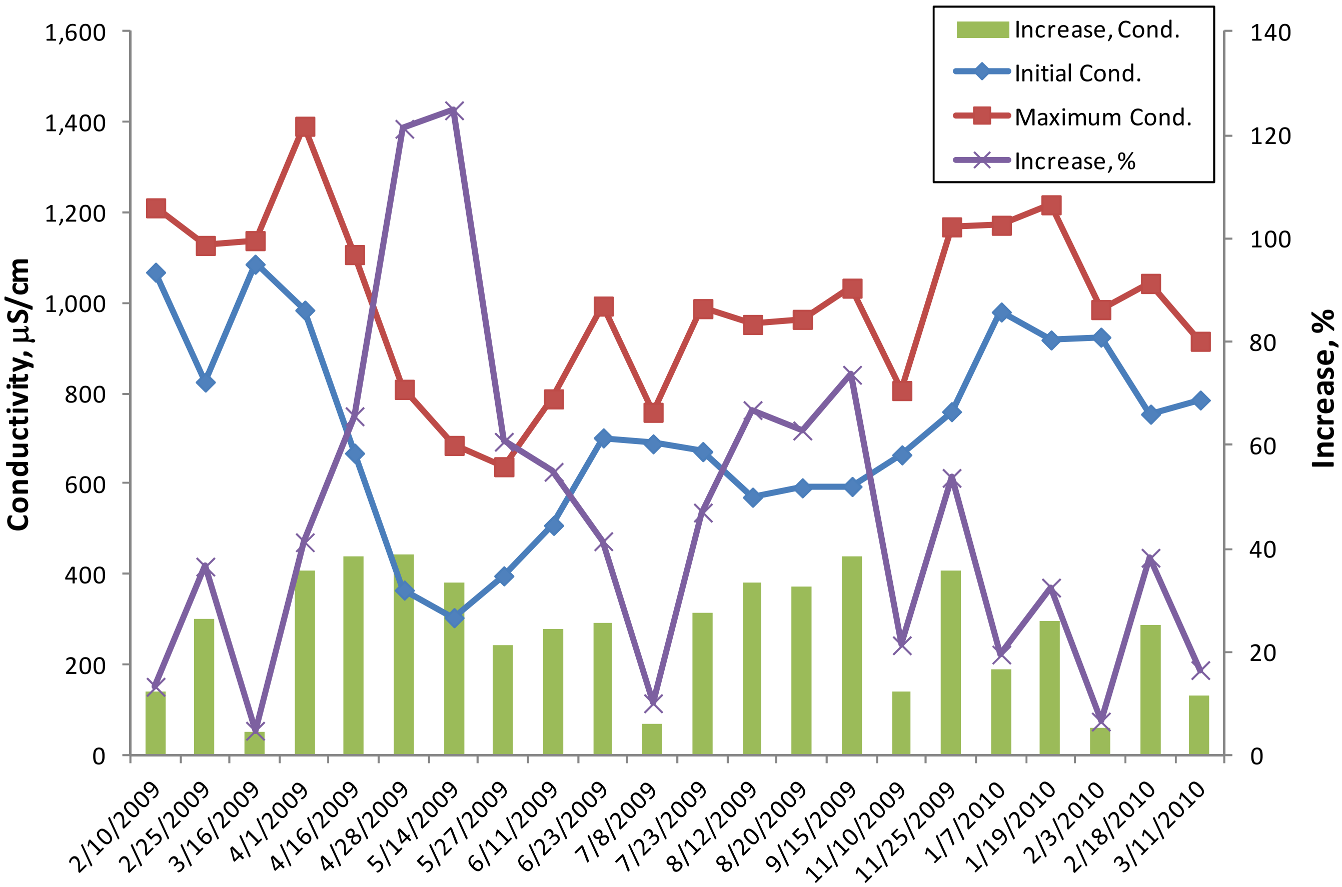

Figure 33. Initial and maximum conductivities for South Old River transects

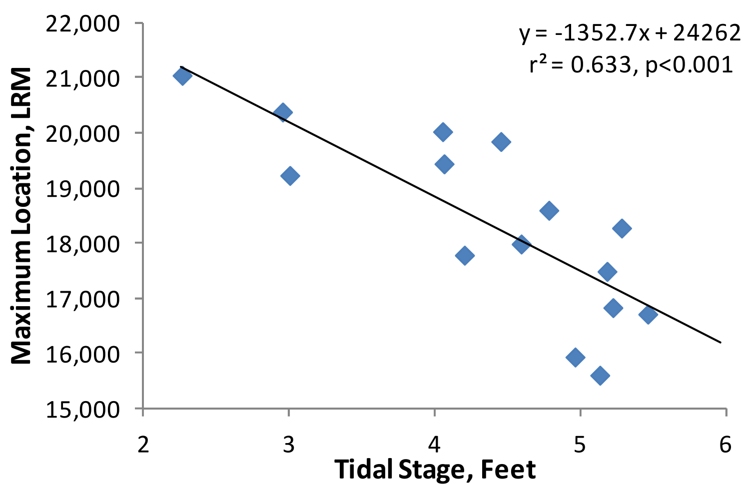

Figure 34. Location of maximum conductivities (LRM = Linear Referenced Meter) in South Old River with tidal stage (CDEC station OAD, above temporary barrier site). Excludes dates when the temporary barriers were completely installed (July 3 to November 19).

Table 9. Summary of water quality in South Old River at the head of Middle River (meter zero) and Tracy Boulevard Bridge (Tracy)

South Old River Station	Statistic 1/	Cond. (µS/cm)	pH (pH Units)	TDS	Calcium	Magnesium	Sodium	Alkalinity 2/	Sulfate	Chloride	Boron	Bromide
Head of Middle River (meter zero)	Minimum	306	7.8	175	17	9	32	51	35	36	0.10	0.11
	Maximum	1,079	9.3	643	51	29	134	149	163	158	0.64	0.54
	Average	769		450	37	20	89	110	102	110	0.42	0.36
	Median	777	8.0	461	38	20	89	111	110	105	0.48	0.34
	Count (#)	22	22	22	22	22	22	22	22	22	22	22
	Standard Deviation	203		128	8.1	5.1	28	22	38	32	0.16	0.11
	Relative Percent SD (%)	26		29	22	25	31	20	38	29	39	31
Tracy Boulevard Bridge (Tracy)	Minimum	451	7.8	259	23	13	50	70	54	59	0.20	0.16
	Maximum	1,257	9.2	753	61	35	149	159	177	194	0.80	0.66
	Average	888		526	44	24	102	121	121	133	0.50	0.40
	Median	911	8.0	542	44	24	103	126	133	130	0.53	0.39
	Count (#)	33	33	33	33	33	33	33	33	33	33	33
	Standard Deviation	208		128	8.8	5.8	27	23	36	34	0.15	0.11
	Relative Percent SD (%)	23		24	20	24	27	19	30	25	30	27

1/ mg/L unless otherwise specified

2/ total alkalinity as $CaCO_3$

between stations were greatest for chloride which made up from 42% to 51% of the anionic content at Tracy versus 39% to 48% at meter zero. The geochemistry at both stations was reflective of more saline conditions in the San Joaquin River. Figure 35 depicts the geochemical makeup at Tracy, meter zero, and Vernalis on the San Joaquin River. Water type at Vernalis varied from calcium-bicarbonate to sodium-chloride with increasing conductivity (conductivity range = 99 to 1,120 µS/cm).

Water quality data from Tracy were not entirely representative of conditions there. Discrete samples did not provide a fully accurate characterization of water passing that station. A more representative measure of the geochemistry at Tracy would be best achieved by using composite sampling techniques. This would account for the transitory nature of passing impacted waters. Isolated slugs of high salinity from Paradise Cut are briefly present as they migrate downstream with tidal flow. Further, water at Tracy is heavily influenced by saline plumes originating from a nearby agricultural drain (SOR16). Inputs from these sources can change the water quality there hourly or quicker. Without accounting for these persistent influences, water quality data from Tracy would not provide an accurate portrayal of the geochemical variations occurring at that station.

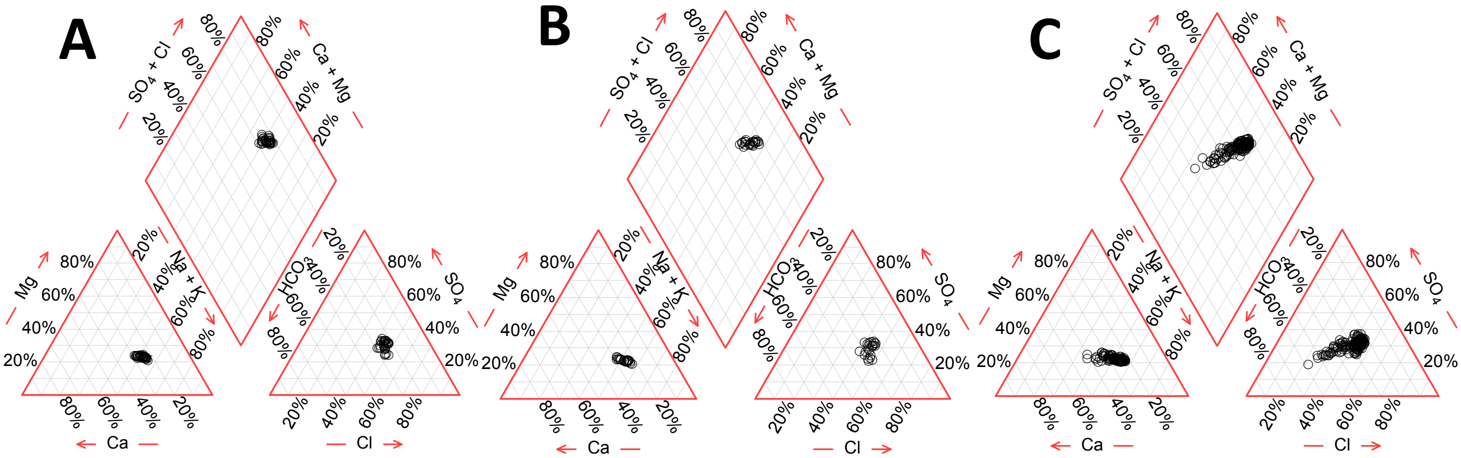

Figure 35. Piper graph depiction of geochemistry in South Old River at Tracy Boulevard Bridge (Tracy, A) and the head of Middle River (meter zero, B). The San Joaquin River at Vernalis is also shown over a wide range of conductivities (range = 99 to 1,120 µS/cm, C) (San Joaquin River data source: DWR's Water Data Library, http://www.water.ca.gov/waterdatalibrary/waterquality/, accessed 11/15/2011).

V. Conclusions

South Old River (SOR) and its tributaries are the receiving waters for approximately 50 discharge sources principally associated with drainage from agricultural lands. Many of the sources exhibit relatively elevated salinities. Major discharge or tributary inputs were apparent in SOR transects as increases in conductivity at specific locations. Conductivity increases and corresponding input locations were linked by linear referenced meter, the standardized distance in meters from the eastern transect boundary (meter zero).

The Tracy Boulevard Bridge compliance station (meter 10,927) was routinely impacted by upstream inputs from Paradise Cut and a nearby agricultural drain. The measured effects by these and other inputs included passing conductivity slugs/spikes, stepped increases (observed between 18% and 49%), or gradually rising trends. Details regarding these effects include:

> Some of the largest isolated conductivity slugs flowing down SOR – as high as 123% of background levels – were shown to originate from Paradise Cut (meter 6,400). They formed when saline water from Paradise Cut was drawn into SOR with declining tide. The downstream-migrating slugs would impact the compliance station by causing wide fluctuations upon passage.
>
> Downstream migrating slugs from Paradise Cut were also decayed by secondary meander channel outflows and tidal dispersion that, combined with the amalgamation of successively generated slugs from previous tidal cycles, created stepped conductivity increases near the compliance station.
>
> Groundwater accretion was shown to be a major source of elevated salts to Paradise Cut. Numerous agricultural drains situated along this waterway also contribute to the salt load.
>
> The compliance station is located immediately downstream from a relatively large pumped agricultural drain (Tracy Boulevard Bridge Drain, meter 10,450) that routinely produced localized plumes of fluctuating conductivity. The drain also created large slugs that temporarily stagnated near the compliance station. Intermittent discharges – in conjunction with bidirectional tidal flux – were also shown to result in gradually rising trends or stepped increases. All of these trends directly affected conductivity at the compliance station.

Conductivity continued to increase downstream from the compliance station due, in part, to the accumulation of multiple other saline inputs.

> One large agricultural drain in western SOR (Bethany Road Drain, meter 17,747) was shown to be primarily responsible for producing large, broad zones of high conductivity. These zones were perpetuated or enhanced over time by a combination of recurring discharges and bidirectional tidal flux. They could be dosed multiple times as they moved back and forth past the discharge mixing region during each successive tidal cycle.

Transect conductivities peaked in the western end of SOR with maximums ranging from 639 to 1,391 µS/cm, a 52 to 444 µS/cm increase (5% to 125%) over initial levels. The increases could largely be attributed to the accumulation of inputs from multiple saline sources (discharges and tributaries) along SOR with considerable influence from the aforementioned discharge source (Bethany Road Drain).

Maximum conductivities were positioned between meters 13,673 and 21,243 – all upstream from the temporary barrier installation site at meter 22,415. These positions and tidal stage were inversely correlated when excluding data within the barrier installation period. The relationship describes a constant re-positioning with tide of maximum salinity zones in western SOR.

Conductivity declined at the westernmost end of all SOR transects due to dilution from lower salinity water shifting up the river with tidal flow. The lower salinity water originates from flows moving north-to-south via cross-Delta waterways and/or Grant Line Canal drawn by south Delta export pumping (DWR 2004). Outflows from SOR were indirectly diluted and eventually intercepted by exports, terminating their continued migration into the Delta.

Discharge or tributary inputs monitored exhibited conductivities of 416 to 6,195 µS/cm (median range = 1,341 to 2,280 µS/cm). Most inputs were composed of drainage from agricultural land south of SOR although source waters also included groundwater, urban runoff, and natural runoff. A limited number of flow measurements ranged from zero to 51.4 cfs. Flows generally increased during the growing season when conductivity was consistently lowest, suggesting salinity declined due to agricultural irrigation activities.

Therefore, although the compliance station at Tracy Boulevard Bridge was routinely impacted by saline discharge and tributary inputs, the greatest impacts (highest conductivities) were measured farther downstream due to the accumulation of multiple other inputs. Based on the data presented here, no one location along SOR is suitable for providing conductivity measurements that are representative of the entire waterway.

Acknowledgements

Special thanks to David Schaap for his tireless dedication in providing design, logistic, and field support. Thanks to Michael Baldwin for flow measurement work, Michael Dempsey for providing equipment assistance, Brian Schreier for initial design/GIS work, and Sid Fong and his staff at Bryte Laboratory for high quality chemical analyses. Supporting assistance from Joe Christen, Cindy Garcia, Dean Messer, and Shaun Philippart.

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Attachment A

Example of flow measurement statistics and quality control results for Wicklund Cut

Discharge Measurement Summary

Date Generated: Fri May 8 2009

File Information

File Name	WICK.508.WAD
Start Date and Time	2009/05/07 10:19:29

Site Details

Site Name	
Operator(s)	MB

System Information

Sensor Type	FlowTracker
Serial #	P217
CPU Firmware Version	3.5
Software Ver	2.20

Units	**(English Units)**
Distance	ft
Velocity	ft/s
Area	ft^2
Discharge	cfs

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.2%	0.6%
Velocity	0.4%	1.4%
Width	0.1%	0.1%
Method	1.4%	-
# Stations	1.5%	-
Overall	**2.3%**	**1.8%**

Summary

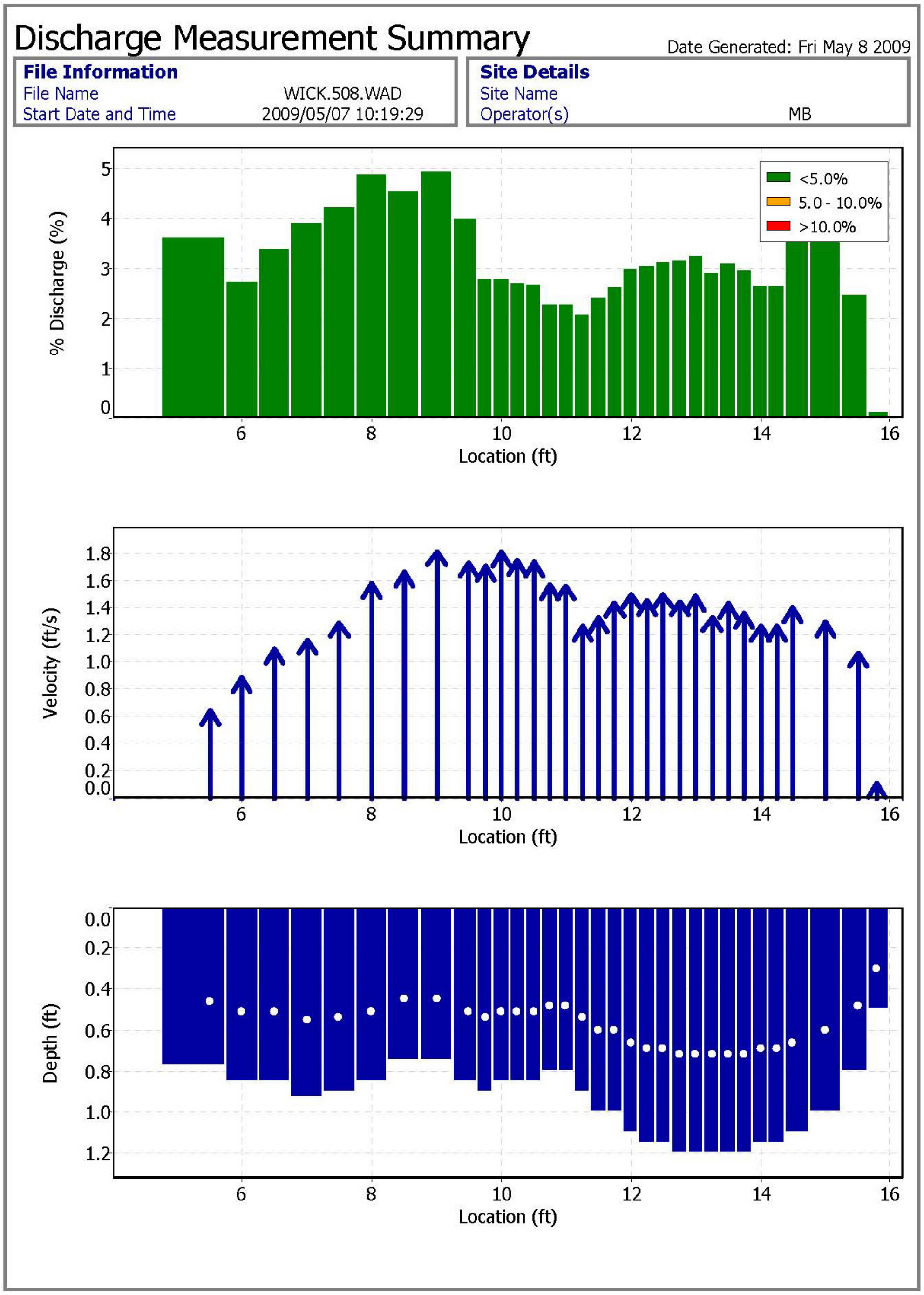
Averaging Int.	30	# Stations	34
Start Edge	LEW	Total Width	12.200
Mean SNR	46.2 dB	Total Area	10.351
Mean Temp	67.54 °F	Mean Depth	0.848
Disch. Equation	Mid-Section	Mean Velocity	1.3333
		Total Discharge	**13.8012**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	10:19	4.00	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0
1	10:20	5.50	0.6	0.775	0.6	0.310	0.6430	1.00	0.6430	0.775	0.4983	3.6
2	10:21	6.00	0.6	0.850	0.6	0.340	0.8871	1.00	0.8871	0.425	0.3771	2.7
3	10:22	6.50	0.6	0.850	0.6	0.340	1.0955	1.00	1.0955	0.425	0.4656	3.4
4	10:23	7.00	0.6	0.925	0.6	0.370	1.1640	1.00	1.1640	0.462	0.5383	3.9
5	10:24	7.50	0.6	0.900	0.6	0.360	1.2900	1.00	1.2900	0.450	0.5805	4.2
6	10:26	8.00	0.6	0.850	0.6	0.340	1.5823	1.00	1.5823	0.425	0.6726	4.9
7	10:27	8.50	0.6	0.750	0.6	0.300	1.6627	1.00	1.6627	0.375	0.6235	4.5
8	10:27	9.00	0.6	0.750	0.6	0.300	1.8173	1.00	1.8173	0.375	0.6815	4.9
9	10:28	9.50	0.6	0.850	0.6	0.340	1.7326	1.00	1.7326	0.319	0.5523	4.0
10	10:46	9.75	0.6	0.900	0.6	0.360	1.7083	1.00	1.7083	0.225	0.3843	2.8
11	10:29	10.00	0.6	0.850	0.6	0.340	1.8136	1.00	1.8136	0.213	0.3854	2.8
12	10:46	10.25	0.6	0.850	0.6	0.340	1.7474	1.00	1.7474	0.213	0.3713	2.7
13	10:30	10.50	0.6	0.850	0.6	0.340	1.7388	1.00	1.7388	0.213	0.3695	2.7
14	10:48	10.75	0.6	0.800	0.6	0.320	1.5715	1.00	1.5715	0.200	0.3143	2.3
15	10:31	11.00	0.6	0.800	0.6	0.320	1.5643	1.00	1.5643	0.200	0.3128	2.3
16	10:49	11.25	0.6	0.900	0.6	0.360	1.2635	1.00	1.2635	0.225	0.2843	2.1
17	10:32	11.50	0.6	1.000	0.6	0.400	1.3297	1.00	1.3297	0.250	0.3324	2.4
18	10:50	11.75	0.6	1.000	0.6	0.400	1.4364	1.00	1.4364	0.250	0.3591	2.6
19	10:33	12.00	0.6	1.100	0.6	0.440	1.5033	1.00	1.5033	0.275	0.4134	3.0
20	10:51	12.25	0.6	1.150	0.6	0.460	1.4554	1.00	1.4554	0.287	0.4184	3.0
21	10:35	12.50	0.6	1.150	0.6	0.460	1.5030	1.00	1.5030	0.287	0.4321	3.1
22	10:52	12.75	0.6	1.200	0.6	0.480	1.4491	1.00	1.4491	0.300	0.4348	3.2
23	10:35	13.00	0.6	1.200	0.6	0.480	1.4869	1.00	1.4869	0.300	0.4461	3.2
24	10:54	13.25	0.6	1.200	0.6	0.480	1.3330	1.00	1.3330	0.300	0.3999	2.9
25	10:37	13.50	0.6	1.200	0.6	0.480	1.4314	1.00	1.4314	0.300	0.4295	3.1
26	10:55	13.75	0.6	1.200	0.6	0.480	1.3619	1.00	1.3619	0.300	0.4086	3.0
27	10:38	14.00	0.6	1.150	0.6	0.460	1.2661	1.00	1.2661	0.287	0.3640	2.6
28	10:56	14.25	0.6	1.150	0.6	0.460	1.2677	1.00	1.2677	0.287	0.3644	2.6
29	10:39	14.50	0.6	1.100	0.6	0.440	1.4012	1.00	1.4012	0.413	0.5780	4.2
30	10:39	15.00	0.6	1.000	0.6	0.400	1.2953	1.00	1.2953	0.500	0.6476	4.7
31	10:40	15.50	0.6	0.800	0.6	0.320	1.0705	1.00	1.0705	0.320	0.3425	2.5
32	*10:43*	*15.80*	*0.6*	*0.500*	*0.6*	*0.200*	*0.1066*	*1.00*	*0.1066*	*0.175*	*0.0187*	*0.1*
33	10:43	16.20	None	0.000	0.0	0.0	0.0000	1.00	0.0000	0.000	0.0000	0.0

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Attachment A (Con't)



Attachment A (Con't)

Discharge Measurement Summary

Date Generated: Fri May 8 2009

File Information

File Name	WICK.508.WAD
Start Date and Time	2009/05/07 10:19:29

Site Details

Site Name	
Operator(s)	MB

Quality Control

St	Loc	%Dep	Message
32	15.80	0.6	High number of spikes: 6
		0.6	SNR (15.0) is different from typical SNR (46.2)
		0.6	High SNR variation during measurement: 7.7,7.3

Discharge Measurement Summary

Date Generated: Fri May 8 2009

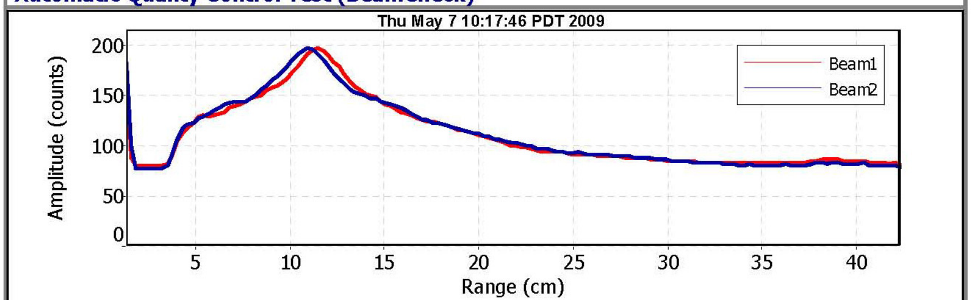
File Information

File Name	WICK.508.WAD
Start Date and Time	2009/05/07 10:19:29

Site Details

Site Name	
Operator(s)	MB

Automatic Quality Control Test (BeamCheck)



- Noise level check - Pass
- SNR check - Pass
- Peak location check - Pass
- Peak shape check - Pass

Attachment B

Quality control analysis for conductivity measurements

Quality control samples for conductivity were periodically collected and sent to DWR's Bryte Chemical Laboratory for analysis. Sampling occurred at meter zero during a majority of the SOR transects. A representative number of samples were also collected from Paradise Cut when boat transects ended at the upper boat-navigated boundary (railroad trestle) and from the five discharge or tributary inputs monitored during this study. Below is a comparative analysis of the results with field measurements.

Relative deviations between field versus laboratory conductivity ([{lab-field}/lab]*100) were plotted in Figures B1 and B2. Figure B1 shows values from transects of SOR at meter zero and Paradise Cut at the upper boat-navigated boundary. Percent differences averaged 1.05% with a median of 1.13% and all but three of the 30 values were within +- 5%. Two of the values outside of +-5% were both measured on the same day. Results from the boat transects conducted on June 11, 2009, were 9.4% at meter zero and 8.3% at the end of Paradise Cut. Field notes indicated complications during meter calibration. In this instance, the meter appears to have consistently underestimated transect conductivities during that day. The other elevated percent difference was for the end of Paradise Cut on July 23, 2009 (-9.4%). The value for meter zero on the same day was -2.3%, so the Paradise Cut field value incurred some form of error in reporting or was subjected to greater-than-normal meter drift.

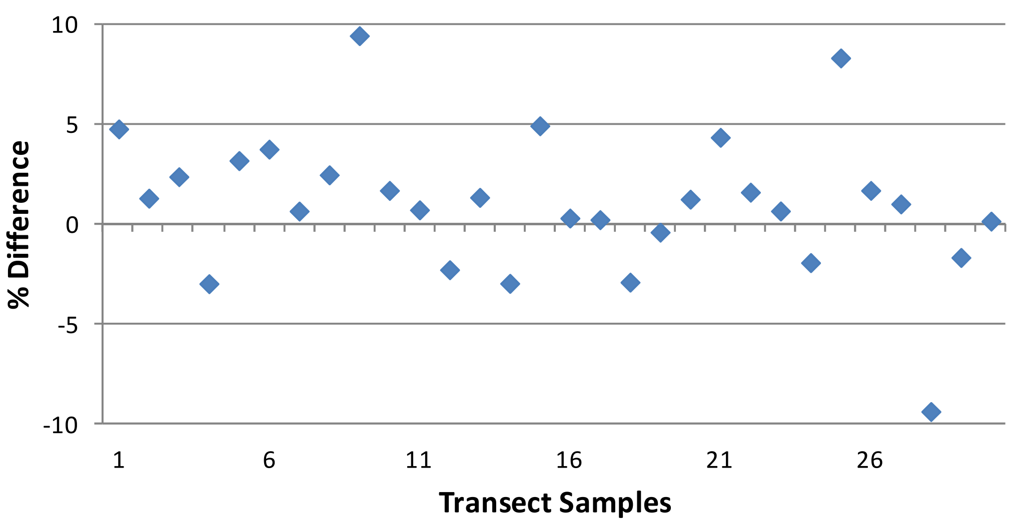


Figure B1. Quality control results from transects on South Old River and Paradise Cut. Percent deviation of field versus lab conductivity ([{lab-field}/lab]*100).

For the input measurements, percent differences averaged -0.41% with a median of 0.17% and all but seven of the 85 values were within +-5% (Figure B2). The greatest difference (-21%) was reported for one measurement from Tracy Boulevard Bridge Drain on February 17, 2010. The relatively high over-measurement of drain field conductivity contrasted with values reported for

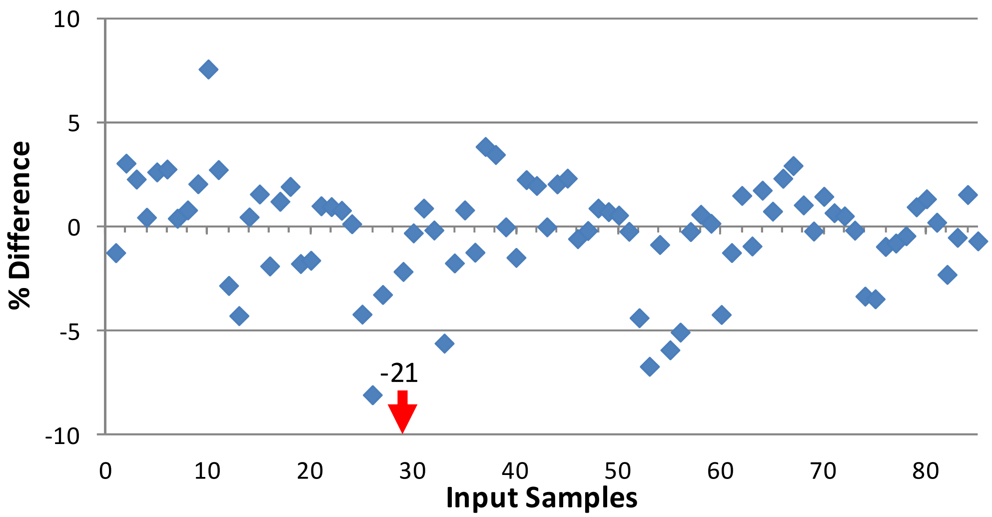


Figure B2. Quality control results from discharge and tributary input sampling. Percent deviation of field versus lab conductivity ([{lab-field}/lab]*100).

the other drains on the same day which exhibited percent differences ranging from -5.9% to -0.8%. Regardless, the field conductivity value associated with the -21% percent difference was removed from the database. Another value outside of the +-5% range was from the same drain (7.6%) and coincided with a lower value (3.9%) from Arbor Road Drain on the same day.